

INTERIM FINAL

**GUIDANCE FOR THE EVALUATION AND MITIGATION
OF SUBSURFACE VAPOR INTRUSION TO INDOOR AIR**

**Department of Toxic Substances Control
California Environmental Protection Agency**

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EXECUTIVE SUMMARY

The intrusion of subsurface vapors into buildings is one of many exposure pathways that must be considered in assessing the risk posed by releases of hazardous chemicals into the environment. The Department of Toxic Substances Control (DTSC) in this guidance document recommends an approach for evaluating vapor intrusion into buildings and its subsequent impact on indoor air quality. Approaches for the mitigation of vapor intrusion are also discussed.

Step-Wise Approach

If volatile organic compounds (VOCs) are present in the subsurface at a site, the vapor intrusion pathway should be evaluated along with the exposure pathways identified in other guidance (Preliminary Endangerment Assessment (PEA) Guidance Manual, DTSC, reprinted 1998; Risk Assessment Guidance for Superfund (RAGS), Volume 1 Human Health Evaluation Manual, Part A, United States Environmental Protection Agency (USEPA) 1989). This approach is applicable to both Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites and Resource Conservation and Recovery Act (RCRA) facilities. Due to the complexity of vapor intrusion, many professional disciplines may be needed to evaluate and mitigate exposure. Accordingly, an appropriate project team should be gathered for all vapor intrusion issues.

The DTSC recommends a step-wise approach as discussed below and depicted in Figure 1 for the evaluation of vapor intrusion. For sites with existing buildings, Steps 1 through 11 apply. For sites with proposed buildings, Steps 1 through 3, 5, 6, 7, and 11 apply.

- *Step 1* – Identify the spill(s) or release(s).
- *Step 2* – Characterize the site.
- *Step 3* – Identify the site as one where vapor intrusion into indoor air may represent a complete exposure pathway (VOCs are detected in the subsurface).
- *Step 4* – For an existing building, identify whether an imminent hazard exists from vapors migrating into indoor air. If none exists,
- *Step 5* – Perform a screening evaluation using the provided default vapor attenuation factors. If a potential risk exists,
- *Step 6* – Collect additional site data.
- *Step 7* – Perform a modeling evaluation using site-specific physical parameters and building parameters as appropriate. If the calculated risk is still significant,
- *Step 8* – For an existing building, prepare an indoor air sampling workplan, which includes an assessment of the utility corridors and the development of a contingency plan for appropriate response actions. Also, conduct appropriate public outreach with the affected community.
- *Step 9* – For an existing building, conduct indoor air sampling.
- *Step 10* – For an existing building, evaluate the data to determine if the indoor air concentrations are acceptable. If they are not,
- *Step 11a* – For an existing building, mitigate indoor air exposure, implement engineering controls, and remediate the VOC contamination as appropriate.
- *Step 11b* - If no building exists on the site, and the calculated risk is significant, remediate subsurface VOC contamination or implement institutional measures to assure that engineering controls are installed in any future buildings.
- *Step 11c* - For both circumstances, institute long-term monitoring at the site.

Steps 1, 2 and 3 – Identifying spills, characterizing the site, and evaluating if the vapor intrusion exposure pathway is complete

Steps 1 and 2 are common to all site investigations, and only guidance for performing these steps when VOCs have been found in the subsurface are discussed here. With respect to Step 3, if VOCs are detected in the subsurface near or adjacent to existing or proposed buildings, then the site should be considered one where the vapor intrusion exposure pathway may be complete.

Step 4 – For an existing, occupied building, identifying an imminent hazard from VOCs migrating into indoor air from the subsurface

The identification of an imminent hazard is based on the presence of odors in the building under investigation and observing illnesses in building occupants (headache, eye irritation, nausea, dizziness, etc.) that may be linked to inhaling hazardous vapors indoors. If any of these circumstances exist, it may be necessary to consider the evacuation of the building.

Step 5 - Performing a Preliminary Screening Evaluation for Vapor Intrusion

A preliminary evaluation should be conducted using the attenuation factors provided by DTSC in this guidance document. With the subsurface contaminant concentrations and default attenuation factors, the associated contaminant concentrations in indoor air can be determined. Default attenuation factors are provided for the following building scenarios:

- Existing residential slab-on-grade buildings
- Existing residential buildings with crawl spaces
- Existing residential buildings with basements
- Existing commercial buildings
- Future residential slab-on-grade buildings
- Future residential buildings with crawl spaces
- Future residential buildings with basements
- Future commercial buildings

The following conditions apply on the use of the default attenuation factors:

- Soil gas measurements should be used.
- Maximum contaminant concentrations should be used.
- Fractured bedrock or other preferential pathways should not exist at the site.
- California toxicity factors should be used.
- Cumulative health effects should be calculated.

The screening evaluation for vapor intrusion should be included as part of the PEA for a site or facility. As discussed by the USEPA in their risk assessment guidance (USEPA RAGS, 1989), the risks from each chemical and from all applicable exposure pathways should be summed to obtain the overall screening level risk posed by chemicals detected at the facility/site.

Additionally, pursuant to Senate Bill 32 (SB 32), the California Land Environmental Restoration and Reuse Act, the Office of Environmental Health Hazard Assessment

(OEHHA) published a list of screening numbers. Numerous exposure pathways were evaluated in calculating the SB 32 screening numbers, including the exposure pathway of inhaling indoor air contaminated with vapors intruding from the subsurface. The OEHHA screening numbers may be used to evaluate sites for vapor intrusion but only with an understanding of the assumptions and limitations of the screening numbers, as indicated in the OEHHA Advisory Document and its associated User's Guide. In addition, the OEHHA screening numbers can be used as a mechanism to assist in the prioritization of work.

Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) are not appropriate exposure endpoints in occupational settings for indoor air degraded by subsurface contamination. However, this guidance does not apply to operations that are directly regulated by OSHA (e.g., spray booths, plating operations, etc.).

Steps 6 and 7 - Collecting Additional Site Data and Performing a Site-Specific Vapor Intrusion Evaluation

If a potentially significant risk is calculated in the preliminary screening evaluation, further investigation may include the following:

- Collecting data to define site-specific soil physical and chemical parameters using recommended test methods.
- Collecting soil gas samples to define the vapor plume at sites where buildings do not exist or near or beneath buildings using current guidelines.
- Statistically evaluating the environmental media data to derive the appropriate contaminant concentration to be used in a site-specific assessment.
- Collecting subslab soil gas samples or crawl space samples at an existing building.

With additional information and data, the risk associated with vapor intrusion can be evaluated with the USEPA Vapor Intrusion Model.

Steps 8, 9 and 10 – Conducting Building Screening, Collecting Indoor Air Samples and Determining if Indoor Air Concentrations are Acceptable (Existing Buildings)

If the site-specific evaluation shows that buildings are subject to vapor intrusion, the occupants of these buildings must be notified. During the notification process, information should be collected concerning the buildings, such as occupancy, preferential migration pathways, consumer product usage, and building characteristics. After the notification process, indoor air samples should be collected and the human-health risk quantified. Buildings should be sampled twice over a six month period before a final risk determination is conducted.

DTSC does not recommend the use of isolation emission flux chamber data for the determination of risk associated with vapor intrusion. Flux chambers may only be used to qualitatively evaluate the flux of vapors migrating from the subsurface into buildings.

Step 11 – Mitigating Indoor Air Exposure and Conducting Long-Term Monitoring

If the indoor air sampling yields unacceptable results, vapor intrusion must be mitigated. There are several remedies that may be considered where vapor intrusion poses a health risk, as follows:

- Removing VOC contamination through site remediation (cleanup).
- Installing passive or active vent systems (existing buildings).
- Installing passive vent systems and a membrane system (future buildings).
- Installing active vent systems and a membrane system (future buildings).

For any remedy chosen for a site, long-term monitoring of soil gas and indoor air may be necessary. The frequency of the monitoring will depend upon site-specific conditions and the degree of VOC contamination.

At some sites, removal of all volatile chemicals from the subsurface will not be possible and institutional controls and engineering measures will be necessary to prevent potential exposure to subsurface vapors. Land use covenants will be required in these cases, which must include the following:

- A description of the potential cause of the unacceptable risk.
- A prohibition against construction without removal or treatment of contamination to approved risk-based levels.
- The implementation and monitoring of appropriate engineered remedies to prevent vapor intrusion until risk-based cleanup levels have been met.

This documentation should be recorded at the local County Recorder's Office after approval by DTSC legal counsel. Additionally, land use covenants must include notification requirements to utility workers or contractors that may have contact with contaminated soil and groundwater while installing utilities or undertaking construction activities.

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INTRODUCTION

Volatile organic chemicals (VOCs) in the subsurface, whether in soil or groundwater, can migrate upward through the soil and enter into buildings, causing an unacceptable chemical exposure for building occupants. The California Department of Toxic Substances Control (DTSC) requires that the human health risk be evaluated at sites under its oversight and, if VOCs are present, exposure from vapor intrusion should be included in the human health risk evaluation. Evaluation of the indoor air exposure pathway involves characterizing subsurface VOC plumes, obtaining appropriate environmental data, using fate and transport models to predict indoor air concentrations from vapor intrusion, and conducting indoor air sampling, if necessary. This Guidance outlines the technical aspects of evaluating this exposure pathway and provides recommendations on elements that should be included in a facility investigation. Due to the complexity of vapor intrusion, many professional disciplines may be needed to evaluate and mitigate exposure. Accordingly, an appropriate project team should be gathered when evaluating vapor intrusion issues.

DTSC anticipates that this Guidance will be used by regulators, responsible parties, environmental consultants, community groups, and property developers. Because vapor intrusion is a developing field, many technical aspects are not well understood. Hence, it is anticipated that many of the procedures and practices within this Guidance will change as our understanding of vapor intrusion progresses. DTSC will update this document as needed to accommodate refinements and advances in our understanding.

SCOPE

This Guidance, along with the vapor intrusion guidance from the United States Environmental Protection Agency (USEPA, 2002a), provides technically defensible and consistent approaches for evaluating vapor intrusion to indoor air, based upon the current understanding of this exposure pathway. Please recognize that this guidance document is not regulation. This Guidance does not impose any requirements or obligations on the regulated community but provides a technical framework for evaluating vapor intrusion. Other technically equivalent procedures may exist, and this Guidance is not intended to exclude alternate approaches or methodologies. Hence, users of this guidance document are free to use other technically sound approaches.

This Guidance addresses the following questions:

- What sites are candidates for vapor intrusion to indoor air?
- What site characterization data are needed to conduct a vapor intrusion evaluation?
- What are the data requirements for an evaluation of indoor air exposure?
- What sites pose an imminent threat and warrant immediate action due to vapor intrusion?
- What is the human health risk associated with vapor intrusion?
- When should indoor air sampling be conducted?
- When are mitigation measures necessary to prevent indoor air exposure?
- When are long-term soil gas and indoor air monitoring required?

This Guidance only addresses the evaluation of a single exposure pathway of vapor intrusion to indoor air. However, when evaluating the human and ecological risk associated with releases of hazardous chemicals to the environment, all potential exposure pathways

should be evaluated and the results reported to DTSC. Mitigation of contaminant exposure must be conducted with an understanding of all exposure pathways, not just the vapor intrusion pathway. As such, this Guidance supplements DTSC's Preliminary Endangerment Assessment (PEA) Guidance Manual (DTSC, 1994) and USEPA's Risk Assessment Guidance for Superfund (USEPA, 1989).

VAPOR INTRUSION EVALUATION OVERVIEW

Figure 1 shows the step-wise approach for evaluating vapor intrusion, and the associated steps are described in the following text. DTSC recommends that a team of technical professionals be gathered when evaluating the exposure pathway. The core team should consist of a geologist, a toxicologist, and an engineer. Since this document cannot address all circumstances, the team can provide technical and management judgment when encountering unusual or complex issues. The step-wise approach in this guidance document is meant to be flexible and may be tailored to site-specific circumstances.

Although volatile chemicals may be present in the subsurface beneath a building, if contaminant vapors do not enter the building, the exposure pathway from the contaminant source to the building occupant (receptor) is deemed incomplete, and the receptors cannot be considered at risk for vapor intrusion. Likewise, subsurface vapors may enter the building but be present at such low levels that the risk is negligible. However, vapors may migrate into a building and accumulate at levels that pose a human health threat. Figure 2 shows a simplified conceptual diagram of vapor intrusion.

Methane is not specifically addressed in this Guidance, although some of the procedures described may apply.

VAPOR INTRUSION ASSESSMENT

For sites with existing buildings, DTSC recommends that Steps 1 – 11 be followed. For sites where no buildings exist but may potentially be built, DTSC recommends that Steps 1 – 3, 5, 6, 7, and 11 be followed (Figure 1). While the assessment process is presented in a step-wise fashion, the vapor intrusion pathway may be evaluated in an iterative manner.

Step 1: Site History and Identification of Spills and/or Releases

A comprehensive evaluation of the current and historical operations at a site should be conducted. Compilation of complete site information is essential for identifying all exposure pathways. DTSC recommends that record reviews be conducted to identify all Areas of Potential Concern (AOPCs) which might affect indoor air quality.

For example, all historical documents should be reviewed to identify the potential locations of releases of the hazardous chemicals to the environment. These documents include, but are not limited to:

- Regulatory Agency Files. Agency files contain information on hazardous chemical releases to the environment. Appropriate agencies to contact are DTSC, USEPA, State Water Resources Control Board (SWRCB), Regional Water Quality Control Boards (RWQCBs), county environmental health departments, city environmental health departments, and local fire departments.

- Site Owner and Operator Records. Facility records are the primary source of information concerning the handling of hazardous chemicals. Owner/Operator files may include such records as product purchase invoices, waste manifests, permits, material safety data sheets (MSDS), safety plans, spill prevention plans, regulatory violations, and product inventory reports.
- Maps and Photographs. Maps and photographs should be reviewed to determine the physical setting of a site and to identify prior property uses. Aerial photographs, historical photographs, and insurance maps should be checked to determine prior site use.

Site inspections should be conducted to locate areas where chemicals were potentially released into the environment. The site inspection should include a walk-through of all known and potential areas of operation. Observations during the site inspection should focus on identifying hazardous materials and hazardous waste management units. Some of the physical features that are indicative of AOPCs are:

- Storage tanks and storage areas
- Areas with odors
- Waste piles
- Pools of liquid
- Electrical or hydraulic equipment
- Unidentified containers
- Drains and sumps
- Stained soil and pavement
- Degraded floors and walls
- Pits, ponds, and lagoons
- Dry wells and injection wells
- Septic systems
- Loading docks or waste transfer areas
- Waste processing areas
- Solvent dipping tanks
- Production lines

All physical features that are unique to the vapor intrusion pathway should be noted during the site inspection. All buildings at a site should be inventoried along with their foundation types (basement, slab-on-grade, crawl space, or earthen floor) and foundation condition. The building dimensions should be noted along with the building construction date. All potential preferential pathways for vapor migration should be documented. Examples of preferential pathways include piping and utility corridors, floor drains, foundation construction joints, and elevator shafts. Uses of adjacent properties should be determined due to potential offsite migration of subsurface contaminant plumes. Additional guidance on the evaluation of site history and the identification of spill and releases can be found in the DTSC PEA Guidance Manual (1994).

Step 2: Site Characterization

Characterization of contamination should be conducted in the lateral and vertical directions through subsurface sampling. Likewise, the subsurface should be tested for all chemicals-of-concern (COCs) as determined through the site inspection process. For the vapor

intrusion pathway, exposure to subsurface contamination is best characterized through the collection of soil gas samples. When there is known or potential groundwater contamination, water samples should also be collected to evaluate the aquifer's ability to degas VOCs, which potentially may cause a vapor intrusion risk.

When evaluating exposure risk to subsurface contamination, a conceptual site model (CSM) should be developed and submitted to DTSC. Contaminant characterization data needed for vapor intrusion evaluation and the associated CSM are described below.

Conceptual Site Model (CSM)

The CSM is part of all site investigations. The purpose of a CSM is to provide a conceptual understanding of the potential for exposure to hazardous contaminants at a site based on the sources of contamination, the release mechanisms, the transport media, the exposure pathways, and the potential receptors. The CSM should include a diagrammatic or schematic presentation that relates the source of contamination to human receptors and identifies all the potential sources of contamination, the potentially contaminated media, and exposure pathways. The CSM organizes and communicates information about the site characteristics and is a necessary component of any health risk assessment. DTSC recommends that the following items be included in a CSM for the vapor intrusion pathway:

- Primary Sources of Contamination. For each potential contaminant source, describe the industrial settings that potentially caused the contamination and provide a list of chemicals released into the environment for all such settings.
- Primary Release Mechanism. For each potential contaminant source, describe the means by which the release, or suspected release, is thought to have occurred.
- Secondary Sources of Contamination. Include all the environmental media potentially contaminated by the primary sources, such as surface soil, subsurface soil, and groundwater. Contaminated building materials, such as concrete foundations, can also be a source for vapor intrusion.
- Contaminant Transport Mechanisms. For each potentially contaminated medium, describe the transport methods to indoor air, which are usually advection and diffusion through the vadose zone, and describe the character of the subsurface through which the contaminants must move.
- Environmental Exposure Media and Exposure Routes. At sites where buildings exist, describe the character of the buildings where vapors may accumulate and any preferential contaminant migration pathways associated with the buildings, such as foundation crack, voids, utility ports, pipes, elevator shafts, sumps, and drain holes.
- Potential Receptors. List all the current and future receptors that could potentially contact contaminated indoor air.

In documenting current site conditions, a CSM should be supported by maps, subsurface cross sections, foundation details, and site diagrams. The narrative description should clearly describe known site conditions and state what assumptions were made to generate the CSM. The narrative should include a description of ambient sources and presence of

nearly potential sources of VOCs, such as soil vapor extraction systems. As additional data are collected and analyzed through the evaluation of the vapor intrusion pathway, the CSM should be updated and distributed to interested parties. The CSM should be an essential decision-making and communication tool for all interested parties. Additional information on the development of a CSM be found in guidance published by the United States Department of Energy (1997).

Soil Gas

Soil gas data should be used to evaluate vapor intrusion to indoor air. Soil gas data are recommended over other data, such as soil matrix and groundwater data, because soil gas data represent a direct measurement of the contaminant that will migrate into indoor air. In order to evaluate vapor intrusion, soil matrix and groundwater data must be converted to vapor concentrations using assumptions about the partitioning of the contaminant into the gas phase. While partitioning equations are readily available, using them increases the uncertainty in evaluating vapor intrusion. DTSC views this increased uncertainty as unacceptable in any indoor air evaluation. Hence, soil gas is the preferred contaminant data to use for calculating the risk from the vapor intrusion pathway. This preference for soil gas data to evaluate vapor intrusion is shared by USEPA (2002) and Johnson and Deize-Abreu (2003). In addition, it may be necessary to collect soil gas samples at two distinct time intervals to compensate for the effects of weather events, such as recent rainfall or barometric fluctuations. Ideally, for sites subject to vapor intrusion, permanent vadose monitoring points for sample collection should be installed to evaluate the long-term behavior of contaminated soil gas.

The California Environmental Protection Agency's (Cal-EPA) Soil Gas Advisory (2003) provides procedures for obtaining high-quality soil gas samples for use in risk assessments. The Advisory recommends the following field activities during the collection of soil gas samples:

- Sample greater than 5 feet below grade to reduce the effects of barometric pumping.
- Seal the surface around the soil gas sampler to prevent ambient air intrusion.
- Conduct leak tests using tracer gas to evaluate ambient air intrusion.
- Conduct tests to determine the optimal purge volume for sampling.
- Purge and sample at low flow rates (less than 200 milliliters per minute).
- Collect samples in Summa™ canisters (USEPA TO Methods), glass bulbs, or glass syringes.
- Avoid soil gas sample collection following significant rainfall events.

Soil gas samples should be collected to delineate the lateral and vertical extent of the subsurface contamination. Open areas at sites should be sampled first, and the sampling should continue towards buildings as indicated by the field data. Also, open areas that are covered with pavement should be sampled as a way to determine if vapors can accumulate underneath structures. When contaminated soil gas is encountered near buildings, soil gas samples should be collected around the perimeter of the building, as close as possible to the foundation. Soil gas samples from preferential pathways, such as utility corridors, should also be collected. Characterization should continue until non-detectable concentrations of VOCs are encountered in the subsurface laterally and vertically. The soil gas samples should be analyzed by gas chromatography / mass spectrometry (GC/MS) methods.

The minimum amount of soil gas sampling needed in the vertical direction to evaluate vapor intrusion is the collection of soil gas samples at 5 and 15 to 20 feet below surface grade. Ideally, subsurface plumes should be delineated laterally and vertically with soil gas samples. In cases where previous characterization activities have taken place with soil matrix sampling without regard for vapor intrusion, additional characterization with soil gas sampling may be warranted. In these cases, the minimum level of soil gas sampling would be sample collection at 5 and 15 to 20 feet below surface grade.

Soil gas samples should not be collected depths shallower than 5 feet in order to minimize barometric pumping effects. Deeper samples should be collected as needed to define vertical trends in vapor concentrations. For sites that overlie contaminated groundwater, an effort should be made to collect soil gas samples from immediately above the capillary fringe zone and half-way to the surface. For sites where the depth to groundwater is less than five feet, an attempt should be made to collect soil gas samples from beneath existing building foundations or similar settings, such as garage floors, patios, parking lots, roads, and other areas that are covered with pavement, concrete or a similar material, as a mechanism to evaluate the potential for vapor accumulation.

The following should be considered when collecting soil gas samples:

- 1) Soil Gas Probes. As appropriate, permanent, semi-permanent, or temporary vadose zone probe points should be installed and monitored to determine temporal soil gas trends. However, during probe installation, subsurface conditions are disturbed. To allow for subsurface conditions to equilibrate, sampling from direct-push probes should not occur for at least 20 to 30 minutes after probe installation and sampling from probe installed with hollow-stem drilling methods should not occur for at least 48 hours after probe installation. Otherwise, the soil gas samples may not be representative of subsurface conditions. For soil gas sample collection, the quality assurance and quality control procedures in Cal-EPA (2003) and Los Angeles RWQCB (1997) should be followed.
- 2) Sampling Density. For sites seeking agency closure with unrestricted future land use, the residual concentrations of VOCs in the subsurface should be protective of residential receptors. Therefore, soil gas sampling locations should be sufficiently dense to effectively evaluate residential building scenarios. Ideally, there should be a soil gas sample for every potential future residential building. The parcel size for most residential housing tracts in California is approximately a quarter acre. Hence, soil gas sampling for future residential developments should be conducted on a quarter acre spacing. Soil gas samples should be collected until the soil gas contaminant plume is fully delineated and a clean zone of 100 feet beyond the extent of the soil gas plume is demonstrated (see Step 3, Criterion Two). For sites where current and future land use will be restricted by a land use covenant, the soil gas sampling density can be increased as a function of the size of the future buildings pursuant to the land use covenant.
- 3) Collection of Duplicates. When collecting soil gas samples with glass bulbs or glass syringes and analyzing the gas samples for VOCs by Method 8260B (USEPA, 1996) modified for air analysis with a mobile laboratory, the results of the field work should be independently confirmed through the collection of duplicate soil gas samples in Summa™ canisters. The collection of duplicates will confirm the mobile laboratory

detection limits and identify other potential COCs at the site. DTSC recommends that ten percent of the soil gas samples collected in the field be confirmed with Summa™ canisters that are analyzed using TO-14A (USEPA, 1999a) or TO-15 (USEPA, 1999b), as appropriate. The Summa™ canister duplicates should be collected in areas of both high and low VOC concentrations.

- 4) Analytical Detection Limits. The analytical detection limits for the soil gas samples should be sufficiently low to adequately evaluate the vapor intrusion pathway. As a conservative approach, the analytical detection limits should be no higher than five hundred times the acceptable indoor air concentrations. Setting a detection limit at this level implies that a soil gas measurement taken at five feet below surface grade that has a non-detectable concentration of a VOC with a detection limit of five hundred times the acceptable indoor air concentration is protective of public health. This assumption is based upon the data gathered by OEHHA (2004). Hence, detection limits derived from this generic attenuation factor should be protective of public health in California. However, in certain site-specific situations, the analytical detection limits must be set lower than five hundred times the acceptable indoor air concentrations if the estimated vapor intrusion attenuation factor dictates the change. This may be the case for soil gas samples collected from depths shallower than five feet or for soil gas samples collected directly below foundation slabs. For chemicals known to exist in the subsurface, whether determined through direct measurement or historical records review, the chemicals should be evaluated for vapor intrusion even if the concentrations in soil gas concentrations are non-detectable. In these cases, the chemical should be evaluated at concentrations equal to the method detection limit. If the chemical is postulated to no longer exist in the subsurface due to biodegradation or volatilization, the analytical detection limits should be appropriately low to demonstrate that circumstance.
- 5) Low Flow Conditions. Since soil gas is the preferred data for making vapor intrusion evaluations, every attempt should be made to collect representative samples. However, it may not be possible to collect soil gas samples from the subsurface in some instances. Some examples include sites with a saturated vadose zone due to a shallow water table or sites underlain with clay-rich soil. For sites with postulated low air permeability, an attempt should always be made to collect soil gas rather than default to another sampling method. However, if soil gas sampling fails, soil matrix samples should be collected pursuant to USEPA Method 5035 (see below) and the vapor intrusion pathway must then be evaluated with soil matrix data along with the groundwater contaminant data, as appropriate. At a given soil gas sampling location point, two attempts should be made to obtain a gas sample. If the first attempt fails, the sampling probe should be withdrawn and re-driven a few feet over from the original location. DTSC considers soil gas sampling to fail when subsurface air flow rates are less than 10 milliliters per minute or when vacuum of 10 inches of mercury (136 inches of water) or greater is obtained. These low flow conditions must exist at numerous sampling points at a site before DTSC will consider the sampling efforts a failure.

If groundwater is encountered during the collection of soil gas samples and it appears that the contamination is in close proximity to the water table, groundwater grab samples should be collected pursuant to USEPA (1997a) to evaluate the potential contaminant impact to the aquifer. If groundwater contamination exists at a site as documented by groundwater grab samples, the installation and sampling of permanent groundwater monitoring wells may be required by DTSC.

During soil gas sampling, the collection of soil matrix samples should be considered for the evaluation of the physical character of the subsurface, such as total porosity, soil moisture, and dry bulk density (see Step 6).

Groundwater

When buildings exist over or near contaminated groundwater, vapor intrusion should be evaluated for this contaminant source. The risk associated with degassing of VOCs from the aquifer should be quantified. Thus, groundwater evaluation requires two steps. First, soil gas data should be collected over the areas of the contaminated groundwater, and the risk associated with the contaminated soil gas should be quantified. Second, groundwater data should be collected, and the risk associated with the contaminated groundwater should be quantified. Quantification of both risks is a way of evaluating which contamination source provides the greatest health threat.

Cal-EPA (1995a,b) and USEPA (2002b) provide procedures for the installation of groundwater monitoring wells and the acquisition of groundwater VOC sample data. DTSC and USEPA guidance should be followed when collecting groundwater samples so that samples representative of aquifer conditions are collected. Some of the recommendations for data acquisition are:

- 1) Screen Placement. Contaminants at the top of the water table, rather than deeper contamination, are responsible for causing potential vapor intrusion problems. Hence, monitoring wells used to make vapor intrusion evaluations should be screened across the air-water interface, meaning the well screens should not be submerged below the top of the water table.
- 2) Screen Lengths. Monitoring wells with long well screens, regardless of screen placement, should not be used to make vapor intrusion evaluations. When sampling long well screens, clean water entering the well screen at depth may dilute the contaminated groundwater near the top of the screen, biasing the sampling results and the associated risk determination. Hence, short screen lengths are preferred for monitoring wells that will be used to make vapor intrusion evaluations. Ideally, the saturated thickness in a well screen should be less than 10 feet.
- 3) Well Installation. Monitoring wells should be designed and installed to yield representative samples of groundwater conditions. Monitoring wells should have proper filter packs, slot sizes, and annular seals.
- 4) Well Development. Monitoring wells should be developed to create an effective filter pack around the well screen, rectify damage to the formation caused by drilling, optimize hydraulic communication between the formation and well screen, and assist in the restoration of natural water quality of the aquifer near the well.
- 5) Well Purging. Prior to sampling, monitoring wells should be purged to remove stagnant casing water from the well that is not representative of aquifer conditions. Wells can be purged by removing the traditional three casing volumes prior to sampling or the well can be purged with low-flow techniques. For low-flow purging, DTSC recommends that the procedures of Puls and Barcelona (1995) be followed.

- 6) Well Sampling. DTSC prefers bladder pumps or submersible pumps to sample groundwater for vapor intrusion evaluation. These pumps minimize the loss of VOCs during sample collection and handling. Likewise, groundwater can be sampled with diffusion bags following the procedures in Interstate Technology and Regulatory Council (2004). Other methods, such as peristaltic pumps and bailers, may cause unacceptable volatilization of chemicals. Peristaltic pumps can exert a strong negative pressure while sampling, potentially degassing the groundwater sample. Bailers may cause aeration of the sample due to continual disturbance of the well water upon sample retrieval.

Soil Matrix

When it is not possible to collect soil gas samples at a site due to low permeability conditions, vapor intrusion should be evaluated with soil matrix sample data and groundwater data, if the groundwater is contaminated. Soil matrix data are less than ideal for evaluating vapor intrusion risk because of the uncertainty associated with using partitioning equations and the potential loss of VOCs during sample collection. Human health risk calculated from soil matrix samples may be biased low due to inherent VOC escape during sample collection (Hewitt, 1994; Hewitt, 1999; Liikala et al., 1996; Vitale et al., 1999). However, in some cases, there may be no alternative. Interested parties should be cognizant of these factors when evaluating the vapor intrusion pathway with soil matrix samples. Although soil matrix data are not recommended for evaluating risk from vapor intrusion into indoor air, soil matrix data may be valuable for defining the source location and, thus, may be necessary to collect for site characterization purposes.

When sampling soil for VOCs, the soil samples should be collected using the procedures with SW-846 Method A (USEPA, 2002c). DTSC has augmented USEPA Method 5035A procedures with additional guidance (DTSC, 2004b), which summarizes all the available soil sampling options. Both USEPA (2002c) and DTSC (2004) provide the minimum requirements and minimum standards to prevent loss of VOCs during sample collection and handling. DTSC encourages interested parties to read and understand both documents before implementing Method 5035A in the field.

Generally, the options available for soil matrix sampling pursuant to Method 5035A are:

- 1) Chemical Preservation in the Field. Tared and labeled VOA vials with polytetrafluoroethylene (PTFE)-lined septum caps with appropriate chemical preservatives are taken into the field. The preservation fluid is either methanol or sodium bisulfate. The selection of the preservation fluid is based on the chemistry of the target compounds and soil, the desired method detection limits, and data quality objectives. The VOA vials with preservative are weighed in the field before sampling activities to verify no preservative loss. Soil subcores are obtained from appropriate sample locations using a field coring device. The soil subcores of appropriate mass are placed into the VOA vials in the field and capped, forming an airtight seal. The vials are re-weighed in the field to determine the sample weight. At the laboratory, the capped VOA vials are re-weighed to verify no preservative loss. The samples are prepared and analyzed with the caps in place. All preservatives, surrogates, internal standards, and matrix spikes are introduced through the PTFE-lined septum caps either manually or mechanically and analyzed with a closed-system purge-and-trap process.
- 2) Soil Sampling with Multi-Functional Sampling Devices. Multi-functional sampling devices (MFSDs) act as both a coring tool and airtight storage container. An example

of a MFSD is the EnCore™ Sampler or the Core N' One Sampler¹. With MFSDs, a small subcore of soil is collected directly into the volumetric storage chamber of the MFSD from a soil core or soil surface, filling it completely with zero headspace. The storage chamber is then capped to form an airtight seal. The intact MFSDs are sealed in a plastic bag for transport to the laboratory at $4 \pm 2^\circ\text{C}$.

- 3) Empty Vial Technique in the Field. Empty, tared and labeled VOA vials with a PTFE-lined septum caps are taken into the field. The VOA vials do not contain chemical preservatives. Soil cores of appropriate mass are placed into the VOA vials in the field and capped, forming an airtight seal. At the laboratory, the capped VOA vials are reweighed to obtain the weight of the soil samples. The samples are prepared and analyzed with the caps in place within 48 hours of sample collection. Otherwise, the vials should be frozen upon receipt at the laboratory and analyzed within seven days of sample collection. All preservatives, surrogates, internal standards, and matrix spikes are introduced through the PTFE-lined septum caps either manually or mechanically and analyzed with a closed-system purge-and-trap process.

Soil samples should not be collected in large bottles, wide-mouthed jars, acetate liners, or brass sleeves. These are not appropriate containers under Method 5035A and are not appropriate sample collection devices for vapor intrusion evaluations.

When characterizing subsurface contamination at a site, both soil gas sampling and soil matrix sampling may be warranted. Soil gas samples will assist in evaluating the risk associated with vapor intrusion, but these samples cannot be used to quantify the human health risk associated with other exposure pathways, such as dermal and ingestion exposure to soil. To evaluate these other exposure pathways, soil matrix sampling is necessary. Thus, if multiple exposure pathways exist at a site as indicated by the conceptual site model, soil gas and soil matrix sampling will be needed.

Passive Soil Gas

Passive soil gas sampling is a qualitative tool. Sampling devices, which house an adsorbent material, are placed in the subsurface and left to collect vapors over a time period of 10 to 15 days, dependent on site conditions. Organic vapors, migrating through the subsurface, encounter the sampling device and are passively amassed onto the adsorbent material. The sampling devices are then retrieved and analyzed.

Passive soil gas sampling can be an effective tool in understanding the vapor intrusion pathway. The composition of subsurface soil gases can be determined from passive soil samples and the location of subsurface plumes can be mapped, particularly edges of plumes to determine if contamination is near existing or future buildings (see Step 4). Passive soil gas sampling methods can also collect soil gas from low-permeability and high-moisture settings, and are capable of detecting and reporting compounds present in very low concentrations. Likewise, passive soil gas samplers can be placed into potential preferential pathways for soil gas migration, such as utility corridors and foundation cracks, to determine if these pathways could affect indoor air quality. However, passive soil gas samples cannot quantify the contaminant concentration in soil gas or be used to determine the flux of contaminants over a given area. The concentration of VOCs on the adsorbent

¹ The mention of trade names or commercial products in this Guidance Document is for illustrative purposes only, and does not constitute an endorsement or exclusive recommendation for use at DTSC sites. Equipment other than that listed may be used provided that the resulting performance meets the project data quality objectives.

material in a passive soil gas sampler, though yielding a contaminant mass value, cannot be directly equated to soil gas concentration and the passive samplers should always be used with this understanding.

Flux Chambers

The flux chamber is a qualitative tool and should not be used for risk determination because of insufficient field validation of the flux chamber for use in the evaluation of vapor intrusion to indoor air. The emission isolation flux chamber yields a direct measurement of contaminant flux at a surface. VOC contamination, whether indoors or outdoors, can be located with flux chambers. Flux chambers can be used to determine if contamination is near existing or proposed future buildings by delineating plumes and plume edges (see Step 4). Likewise, flux chambers can be used indoors to determine if foundation cracks are entry points for contaminated soil gas into buildings. In evaluating vapor intrusion, flux chamber results represent an additional line of evidence for evaluating subsurface contamination. Appendix A contains additional information on flux chambers.

Step 3: Is a Site a Candidate for Vapor Intrusion?

To evaluate if a site is a candidate for vapor intrusion, two criteria are considered concerning the nature of the subsurface contaminants and the location of existing or proposed buildings relative to the location of subsurface contaminants.

Criterion One: The chemicals in the subsurface must be volatile and toxic to present a vapor intrusion risk.

The chemicals in Table 1 may be found at sites and are volatile and toxic enough to pose an indoor air risk. If a site contains any of the chemicals listed in Table 1, the site should be evaluated for vapor intrusion. The chemicals in Table 1 were taken from the USEPA Vapor Intrusion Guidance Document (USEPA, 2002a), with the addition of fuel oxygenates and two volatile polychlorinated biphenyl (PCB) congeners (monochlorobiphenyl and dichlorobiphenyl) (Davis et al., 2002; Davis and Wade, 2003).

Soil gas, soil matrix, and groundwater should be tested for all the chemicals of concern at a site. Analytical detection limits should be sufficiently low to allow for evaluation of vapor intrusion. Hence, when determining if the vapor intrusion pathway is complete at a site based on the occurrence of the chemicals in Table 1, the analytical detection limits must be appropriate (See Step 2 – Soil Gas).

If the chemicals listed in Table 1 are not present at a site, vapor intrusion is not possible and no further consideration of this exposure pathway is needed.

Criterion Two: The existing or future buildings at a site must be close to subsurface contamination so that vapor migration into indoor air is possible.

For existing or future buildings not to be considered a candidate for vapor intrusion, the buildings must be greater than 100 feet away laterally from subsurface contamination (USEPA, 2002a). If buildings are not located near areas of concern, vapor intrusion is not possible and no further consideration of the exposure pathway should be needed. To determine if a building is 100 feet from a groundwater or soil gas contaminant plume, the horizontal distance from the edge of the building to the edge of the contaminant plume

should be measured. The lateral edge of the contaminant plume should be interpolated from the site characterization data with the edge of a plume defined by appropriate analytical detection limits.

Evaluations of building distance from contaminant plumes should only be conducted if the movement of subsurface contamination has reached steady-state conditions. Meaning, these evaluations should only be conducted when the maximum migration potential of the subsurface plumes have been reached. For groundwater, the migration potential can be evaluated with data from routine sampling of groundwater monitoring wells. If the temporal contaminant trends from the monitoring wells indicate stable or decreasing contaminant trends, the maximum contaminant migration for groundwater has probably occurred. For soil gas, a similar evaluation can be conducted if routine sampling data is available from permanent or temporary sampling points. If there are no temporal soil gas data, the length of time to reach steady-state conditions must be estimated from the chemical release date. Knowing that soil gas moves by diffusion at a rate of approximately 25 feet per year (Hartman, 2004), the length of time needed for soil gas to travel from the chemical release point to the building in question can be estimated and compared to the date of the chemical release. If a sufficient amount of time has passed since the chemical release date to allow for diffusional movement to the building in question, then steady-state conditions have probably transpired. If contaminant plumes, whether in soil or groundwater, are increasing, 100 feet is not an appropriate distance between buildings and plumes for evaluating vapor intrusion.

When evaluating the distances between subsurface contaminant plumes and buildings, it is important to consider whether preferential pathways exist which could allow vapors to migrate more than 100 feet laterally. These preferential pathways could be either natural or anthropogenic. Examples of preferential pathways include fractures, macropores, utility conduits, and subsurface drains (See Step 8 – Utility Corridor Assessment). Buildings with preferential pathways should be evaluated for vapor intrusion even if they are further than 100 feet from the contamination.

Step 4: Evaluation of Acute Hazard in an Existing Building

If a site is a candidate for vapor intrusion pursuant to Step 3, the site should be reviewed to determine if immediate action is necessary to verify or abate acute threats to human health. Indicators of acute threats are shown below, but other indicators may also exist.

- Odors. Odors reported by building occupants may be an indication of vapor intrusion. The presence of odors does not necessarily correspond to adverse health effects or safety concerns, but it is prudent to investigate any reports of odors because many odor thresholds exceed their respective acceptable indoor air concentrations.
- Physiological Effects. Exposure to vapors may cause headaches, nausea, eye and respiratory irritation, vomiting, and confusion. Sensitivity to these effects can vary greatly from one person to the next. Individuals most affected by vapors are children, the elderly, and people with pre-existing respiratory conditions such as asthma or bronchitis. These physiological effects may or may not be attributable to vapor intrusion but should be evaluated. In all cases involving physiological effects, the individuals should consult their physician.

- **Wet Basements.** Buildings with basements over shallow groundwater are very prone to vapor intrusion. Basements with evidence of shallow groundwater, such as basements subject to frequent flooding, basements with wet walls during the rainy season, and basements built with moisture barriers, should be scrutinized closely for potential acute health threats. This is especially true for sites with significant subsurface contamination, such as the occurrence of non-aqueous phase liquid (NAPL) floating on the water table.
- **Fire and Explosive Conditions.** The potential for fire and explosion from vapor intrusion should be evaluated. Fire and explosion concern is often raised with petroleum vapors. The lower explosive limit for gasoline vapor is 1.4 percent, or approximately 50,000 times higher than its corresponding odor threshold, thus making it an easily identifiable threat at petroleum release sites. Fire and explosion hazards related to chlorinated solvent vapor intrusion to indoor air are also easily identifiable. Very strong solvent odors would accompany flammable levels, which are approximately 1000 times higher than the odor threshold. Nonetheless, however unlikely an explosion or fire might be, it must be evaluated, particularly if the odors are strong within a building.

Buildings with odors, occupants with physiological effects, and/or wet basements should be evaluated and the indoor air tested as soon as possible using procedures outlined in Step 8 of this guidance document. The results of the indoor air sampling should be evaluated pursuant to Step 9 and, if needed, the measures within Step 10 should be implemented to mitigate the vapor intrusion risk.

DTSC recommends that the buildings with potential fire and explosive conditions be immediately evacuated and the local fire department be contacted. Re-occupancy of the buildings should only be granted with concurrence of the local fire department. After re-occupancy, Step 8, 9, and 10 should be followed as appropriate to evaluate vapor intrusion.

For sites that have potential methane intrusion issues, DTSC's guidance on methane should be consulted and followed as appropriate (DTSC, 2004a), in conjunction with this guidance document.

Step 5: Preliminary Screening Evaluation

If evaluation of a site pursuant to Steps 1 - 4 indicates a potential vapor intrusion problem, a preliminary evaluation of the site should be conducted using the attenuation factors provided by DTSC in this Guidance. In addition, the screening numbers for soil gas developed pursuant to SB 32 by OEHHA can be used as a mechanism to evaluate and prioritize sites subject to vapor intrusion (see below for additional information).

Attenuation Factors for Preliminary Screening Evaluations

To evaluate vapor intrusion with subsurface contaminant data, the attenuation factor (α) for a given building must be determined. The attenuation factor represents the ratio between indoor air concentration and soil gas concentration, as follows:

$$\alpha = \frac{C_{\text{indoor}}}{C_{\text{soil gas}}}$$

where:

$$\begin{aligned} C_{\text{indoor}} &= \text{Indoor air concentration (ug/m}^3\text{)} \\ C_{\text{soil gas}} &= \text{Soil gas concentration (ug/m}^3\text{)} \end{aligned}$$

DTSC recommends that the default attenuation factors in Table 2 be used along with the maximum detected soil gas concentration for preliminary screening evaluations. Default attenuation factors are provided for three foundation configurations; slab-on-grade, crawl space, and basement. The derivation of the default attenuation factors is provided in Appendix B. These default attenuation factors reflect reasonable worst-case conditions for California for the contamination of indoor air due to intrusion of vapors migrating from subsurface contamination. Hence, after lateral and vertical delineation of the subsurface contamination and determination of all the chemicals of concern at the site, a preliminary evaluation for vapor intrusion can be conducted with just the subsurface soil gas concentration data. Using the above equation, the indoor concentration of the chemicals at the site can be calculated. The associated cumulative health risk can be quantified using either the OEHHA indoor air screening numbers pursuant to SB 32 or the procedures described in Appendix C.

The default attenuation factors assume the following conditions for their use in evaluating an existing or future building:

- The subsurface is reasonably homogeneous (uniform).
- No fractures exist in the subsurface.
- Groundwater is greater than 10 feet below surface grade.
- Fluctuations of the groundwater surface are minimal.
- Non-aqueous phase liquid (NAPL) is not present on the water table.
- Preferential pathways do not exist.
- Biodegradation of vapors is not occurring.
- Contaminants are homogeneously distributed.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.
- Building ventilation rates and the indoor-outdoor pressure differentials are constant.
- Model assumptions are representative of site conditions.

If the above conditions exist at a site and the evaluation of the subject building with default attenuation factors results in an acceptable cumulative human health risk, no further consideration is needed for this exposure pathway. However, if the above conditions do not exist when evaluating for vapor intrusion, the default attenuation factors should not be used. Instead, DTSC recommends proceeding to Step 6 and conducting a site-specific screening evaluation.

Use of Soil Matrix Concentrations

An attempt should always be made to collect soil gas samples rather than to automatically defer to soil matrix sampling. Nevertheless, when soil gas sampling fails at a site due to a shallow water table or the presence of clay-rich soil, the vapor intrusion risk may be evaluated using soil matrix sample data (see Step 2 – Soil Matrix). Soil matrix samples should be collected using the procedures in USEPA Method 5035A and the associated soil gas from the soil matrix data should be determined using the partitioning calculation procedures in Appendix E. Quantifying human health risk from Method 5035A soil matrix samples may yield results that are biased low due to inherent VOC escape during sample

collection (Hewitt, 1994; Hewitt, 1999; Liikala et al., 1996; Vitale et al., 1999). Under no circumstances should the risk associated with vapor intrusion be conducted with soil matrix samples collected by non-Method 5035A procedures.

Use of Groundwater Concentrations

While soil gas is the preferred data for the evaluation of the vapor intrusion, sites can be screened, in certain circumstances, with only groundwater contaminant data. In these limited cases, preliminary screening evaluations should be conducted using the default attenuation factors in Table 2. When performing preliminary vapor intrusion evaluations with groundwater data, the associated soil gas originating from contaminated groundwater must be determined, as follows:

$$C_{\text{soil gas}} = C_{\text{groundwater}} * H_c * C_t$$

where:

$C_{\text{soil gas}}$	=	Soil gas concentration (ug/m ³)
$C_{\text{groundwater}}$	=	Groundwater concentration (ug/L)
H_c	=	Henry's law constant (unitless)
C_f	=	Conversion factor (1000 L/m ³)

Screening for vapor intrusion with groundwater contaminant data should only be conducted for existing or future buildings that are far removed from the original source of the contaminant release. DTSC anticipates that the screening for vapor intrusion with groundwater contaminant data will only occur in the downgradient portions of lengthy chlorinated solvent plumes. When evaluating the downgradient portions of groundwater plumes for vapor intrusion, no vadose zone contamination should exist other than the VOC contamination due to groundwater degassing. Evaluations using groundwater data should only occur in portions of a groundwater plume where there is no evidence of non-aqueous phase liquid (NAPL) entrained within the water table aquifer. That is, VOC concentrations in groundwater for these evaluations should be less than one percent of their pure-phase solubility, which is an indicator of NAPL pursuant to Pankow and Cherry (1996).

The groundwater data for these evaluations should meet the following requirements:

- The groundwater monitoring wells are properly drilled, constructed and developed, and the wells are screened across the water table (see Step 2).
- The well screen lengths within the water table are sufficiently short (<10 feet) to yield representative samples of the uppermost water-bearing zone.
- The groundwater samples collected for analysis are representative of aquifer conditions.
- The contaminant trends in individual groundwater monitoring wells are adequately established with an appropriate amount of sampling.
- The analytical detection limits for the groundwater samples are at or below the Maximum Contaminant Levels (MCLs).
- The density of the groundwater monitoring network is sufficient to accurately extrapolate groundwater isoconcentration contours throughout the area of interest.

The intent of establishing contaminant trends within monitoring wells prior to screening groundwater for vapor intrusion is two-fold. First, the degree of natural temporal variability

of the VOC contamination must be established so that an appropriate contaminant input concentration can be used for modeling purposes. Second, the stability of the VOC plume must be demonstrated so that the risk to receptors would not be expected to increase due to contaminant migration.

The evaluation of vapor intrusion should not be conducted with groundwater grab samples due to the inability to place the sampler at the top of the water table and the inability to establish temporal contaminant trends with such data.

For sites with both vadose zone and groundwater contamination, the vapor intrusion risk associated with both contaminated media, soil gas and groundwater, should be provided to DTSC. The vapor intrusion risk associated with both contaminated media should be approximately the same and risk management decisions should be based on the higher of the two values. Additionally, if the risk from the respective contaminated media differ greatly, an explanation of this occurrence should be provided to DTSC.

Use of Soil Gas Screening Numbers from the Office of Environmental Health Hazard Assessment

Pursuant to Senate Bill 32 (SB 32), the California Land Environmental Restoration and Reuse Act, OEHHA published a list of screening numbers for specific contaminants. A screening number is defined in SB 32 as meaning the concentration of a contaminant published by an agency as an advisory number and the screening numbers are for the protection of public health and safety. The screening numbers required by SB 32 are not intended as mandatory cleanup standards for use by regulatory agencies that have authority to require remediation of contaminated soil. SB 32 states:

A screening number is solely an advisory number, and has no regulatory effect, and is published solely as a reference value that may be used by citizen groups, community organizations, property owners, developers, and local government officials to estimate the degree of effort that may be necessary to remediate a contaminated property. A screening number may not be construed as, and may not serve as, a level that can be used to require an agency to determine that no further action is required or a substitute for the cleanup level that is required to be achieved for a contaminant on a contaminated property. The public agency with jurisdiction over the remediation of a contaminated site shall establish the cleanup level for a contaminant pursuant to the requirements and the procedures of the applicable laws and regulations that govern the remediation of that contaminated property and the cleanup level may be higher or lower than a published screening number.

Numerous exposure pathways were evaluated in calculating the SB 32 screening numbers, including the vapor intrusion to indoor air exposure pathway. Hence, OEHHA developed soil gas screening numbers for vapor intrusion for many of the VOCs found in Table 1. The OEHHA screening numbers may be used to evaluate sites for vapor intrusion but only with an understanding of the assumptions and limitations used in the development of the screening numbers. We encourage interested parties to read and understand the OEHHA Advisory Document, along with its associated User's Guide, before using the SB 32 screening numbers at a particular site. See the Cal-EPA website for the SB 32 Advisory Document and User's Guide (www.calepa.ca.gov).

The SB 32 soil gas screening numbers may be used to evaluate the vapor intrusion pathway for sites contaminated with VOCs. The SB 32 soil gas screening numbers are intended to be conservative and, under most circumstances, correspond to VOC concentrations that are

assumed to not pose a significant health risk to people who are subject to indoor vapor exposure. The presence of a chemical in soil gas at concentrations greater than the SB 32 screening number does not necessarily indicate that adverse human health effects are occurring. It simply indicates that a potential for adverse risk may exist and that additional evaluation may be warranted. The need for additional investigation and possible cleanup of affected areas may then proceed on a more site-specific basis. This step-wise approach can help expedite judgments about the degree of effort necessary to remediate contaminated properties and restore the properties to productive use. Also, the screening numbers can be used to assist in the prioritization of work.

The SB 32 screening numbers should be used with an understanding of the assumptions and limitations presented in the OEHHA Advisory Document and its associated User's Guide, as discussed below:

- The SB 32 soil gas screening numbers for vapor intrusion only address a single exposure pathway. When evaluating the human and ecological risk associated with releases of hazardous substances to the environment, all potential exposure pathways should be evaluated. Mitigation of contaminant exposure must be conducted with an understanding of all exposure pathways, not just the vapor intrusion pathway.
- The SB 32 screening numbers for vapor intrusion represent a concentration of a single VOC in soil gas for a carcinogenic risk of 1×10^{-6} and a hazard quotient of 1.0. Hence, for sites with a release of a single chemical into the environment, the screening numbers can be easily used to evaluate potential health effects. However, for sites with multiple contaminants, human health effects are cumulative and these cumulative health effects must be calculated.
- A cumulative target risk level other than a carcinogenic risk of 1×10^{-6} and a hazard index of 1.0 may be appropriate for a site.
- The use of the SB 32 screening number is entirely voluntary on the part of the responsible party and subject to the approval by the overseeing regulatory agency. At sites where cleanup of contaminated soils to meet the SB 32 levels would be very costly, the time and effort to develop more site-specific, and presumably less stringent, cleanup levels is usually warranted.
- The SB 32 screening numbers for vapor intrusion should not be used to determine when impacts at a site should be reported to a regulatory agency. All releases of hazardous substances to the environment should be reported to the appropriate regulatory agency in accordance with governing regulations.

Use of Occupational Safety and Health Administration (OSHA) Standards

The OSHA Permissible Exposure Limits (PELs) are not an appropriate standard for evaluating the risk associated with vapor intrusion to indoor air in California pursuant to the California Health and Safety Code. Hence, for vapor intrusion sites, potential adverse effects to humans should be evaluated in terms of acceptable exposure based upon risk rather than upon comparison to OSHA PEL endpoints. One exception where OSHA PEL endpoints may be considered is for operating RCRA facilities pursuant to USEPA's Environmental Indicators (EI) Program under the Government Performance and Results Act

of 1993. USEPA allows the use of OSHA PELs, as an interim measure, at operating RCRA sites to evaluate progress on correction action activities (USEPA, 2003a). Also, various operations at RCRA and non-RCRA sites are directly regulated by OSHA (e.g., spray booths, plating operations, etc.), and this Guidance does not apply to those specific operations. The use of OSHA PELs and USEPA's Environmental Indicators Program is further discussed in Appendix F.

At sites subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), cleanup levels are generally determined either by Applicable or Relevant and Appropriate Requirements (ARARs) or the risk assessment process. OSHA standards are not ARARs under CERCLA statute and regulations. Therefore, OSHA standards should not be applied to CERCLA cleanups.

When a Preliminary Screening Evaluation Indicates an Unacceptable Risk

These are the options for a site if the risk due to vapor intrusion is unacceptable by a preliminary screening evaluation:

- Conduct an evaluation of vapor intrusion with appropriate site-specific data (Steps 6 and 7).
- Collect indoor air samples to substantiate exposure from vapor intrusion as indicated by the preliminary evaluation (Steps 8 - 10).
- Remediate the subsurface contaminants to acceptable levels as determined by the preliminary evaluation (Step 11).
- Institute engineering controls to mitigate the exposure (Step 11).

Step 6: Additional Site Characterization

For a site that does pass a preliminary screening evaluation, a site-specific evaluation of vapor intrusion may be warranted. Additional site characterization may be needed to better delineate the soil gas concentrations at a building subject to potential vapor intrusion. Also, it may be prudent to measure the physical properties of the soil at a site to better understand the behavior of contaminant migration. For sites with existing buildings, one can sample the soil gas directly under the building foundation (sub-slab) or sample the air in the area of the raised foundation (crawl space). Each option is discussed separately below.

Additional Soil Gas Sampling

Where a building exists, ideally, soil gas samples should be taken under the building due to the potential for vapor accumulation under the foundation (Johnson and Deize-Abreu, 2003). In many cases, this will not be practical and, hence, the samples should be collected as close to the building as possible. At a minimum, soil gas samples should be collected at two locations, along opposite sides of the building. Large buildings should have more sampling points. The soil gas sampling should be started at 5 feet below surface grade and continue at 5 foot intervals, if possible, until the soil gas has been delineated vertically. For the collection of soil gas adjacent to offsite buildings, the execution of an agreement with the

offsite property owner for access may be warranted. A sample access agreement can be found in Appendix J.

For future buildings, the soil gas sampling should occur on a 100 foot grid, or at a higher density so there is at least one soil gas sample associated with each potential building location. Hence, for future residential developments, the sampling grid might be fairly dense. The soil gas sampling should extend 100 feet beyond any potential building footprint pursuant to USEPA (2003a) (see Step 3, Criterion Two).

Physical Characteristics of the Subsurface

Soil samples can be collected for evaluation of the physical character of the subsurface. Soil cores, if taken, should be submitted to a geotechnical laboratory for site-specific determination of bulk density, grain density, total porosity, grain size, moisture content, and fraction organic carbon. The recommended methods for laboratory analysis are described in Appendix H. Enough samples should be taken so that the data can be statistically evaluated.

The air permeability of the vadose zone should be determined from in-situ measurements rather than from laboratory measurements. In-situ measurements test a larger portion of the subsurface than a laboratory measurement. At the laboratory, core analysis for air permeability usually involves subjecting the soil core to a confining pressure which may bias the results low by potentially reducing the pore space within the soil core. In-situ measurements of air permeability should be conducted in the shallow vadose zone, the area of the vadose zone subject to advection by building-driven depressurization. The method for determining air permeability in the field during the collection of the soil gas samples is described in Appendix I.

Additionally, information on the subsurface soil and engineered fill directly underneath the foundation of existing buildings should be obtained from the building's geotechnical report. Reports usually contain geotechnical laboratory and engineering data for the native soil and fill material, along with fill thicknesses. The permeability of the subgrade material, rather than deeper soil, can control the rate at which vapors will be pulled through the foundation and into the building.

Subslab Soil Gas Sampling (Existing Building)

When contemplating the decision to conduct indoor air sampling, subslab soil gas sampling directly below the building foundation should also be considered. Subslab soil gas data, which is collected from the engineered fill directly under the foundation slab, indicate whether contaminants have accumulated directly under the building and which specific chemicals will degrade indoor air quality. Once subsurface vapors move directly under a building, the ability of the vapors to further attenuate is greatly reduced. The subslab air is within the advective envelope of the building-driven depressurization. The monitoring of the subslab soil gas is potentially less costly than monitoring indoor air quality. However, to evaluate the risk associated with subslab soil gas concentrations, the contaminant attenuation over the foundation slab must be known in order to determine the associated indoor air concentrations. If the attenuation factor associated with the building slab is unknown or cannot be determined, USEPA (2002a) recommends that an attenuation factor of 0.1 be used. However, empirical data shown at the 2004 Conference of the Association of Environmental Health and Science suggested that subslab attenuation factors may be closer to 0.01 (Dawson, 2004). Accordingly, an attenuation factor of 0.01 should be used

when evaluating subslab concentrations for vapor intrusion. When collecting subslab samples, the analytical detection limits should be appropriately low to effectively evaluate the indoor air risk.

If proceeding directly to subslab sampling after preliminary screening, additional site characterization may not be necessary for the evaluation of vapor intrusion. That is, further characterization of the subsurface soil gas around the building, determination of the physical character of the vadose zone through geotechnical testing, and site-specific vapor intrusion modeling may not be needed. Hence, proceeding with subslab sampling, while intrusive to building occupants, may shorten the timeframe for evaluation of the exposure pathway and may help reduce the overall cost of a vapor intrusion evaluation.

Methods and procedures for taking subslab samples are described in Appendix G. The collection of subslab samples can be invasive to building occupants, since it requires the removal of floor coverings and coring or drilling of the foundation slab. If chemicals are detected in subslab soil gas, installation of permanent sampling points may be necessary to determine the temporal variability of the data. It should be noted that the method employed to conduct subslab sampling creates a potential preferential pathway, and care should be taken to properly seal the sampling location upon installation. If subslab sampling is conducted, an appropriate number of samples should be taken to characterize the subslab area. At least two subslab samples should be taken, with one sample taken in the center of the building's foundation. For large foundations greater than 5000 square feet, DTSC suggests that one subslab sample per 1000 square feet be collected. If indoor air sampling is subsequently needed, the indoor air samples should only be analyzed for the chemicals detected in the subslab soil gas.

Sampling of Crawl Spaces (Existing Buildings)

Air within a crawl space can be sampled as a substitute for subslab sampling or indoor air sampling. Crawl space air should be less affected by the lifestyle choices, such as household product use and smoking, of the building's occupants than indoor air. Hence, the evaluation of the results of crawl space air sampling should be easier to interpret than indoor air sampling results. For evaluating the human health risk associated with crawl space air, an attenuation factor of 1.0 should be used for crawl spaces, which is consistent with USEPA guidance (2002a). Thus, the indoor air quality is assumed to be equal to the crawl space air quality for evaluation purposes.

When conducted either subslab or crawl space sampling, appropriate public outreach should be conducted (see Public Outreach – below)

Step 7: Site-Specific Screening Evaluations

If evaluation of a site pursuant to Steps 1 - 6 indicates a potential vapor intrusion problem, a site-specific evaluation of the site may be conducted using appropriate fate and transport modeling. DTSC recommends that the USEPA version of the Johnson and Ettinger (J/E) (1991) model be used (USEPA Vapor Intrusion Model, USEPA, 2003). The USEPA Vapor Intrusion Model should be used to simulate site conditions using reasonable, site-specific input parameters.

Use of USEPA Vapor Intrusion Model Spreadsheets

The J/E model is a fate and transport model that calculates an attenuation factor (α ; ratio of indoor air concentrations to subsurface soil gas concentrations). The model simulates the transport of soil vapors in the subsurface by both diffusion and advection into indoor air. Hence, by inputting the soil gas concentration, the model estimates the associated indoor air concentration. In September 1998, USEPA programmed the J/E model into Microsoft EXCEL™ and added a health risk component that calculates the risk from inhaling the specific chemical at the concentration estimated in indoor air. Individual spreadsheets were generated for different contaminated environmental media: soil gas, soil matrix, and groundwater. Version 3.0 of this spreadsheet model was released in 2003. Model results are provided as a risk-based soil, soil gas, or groundwater concentration protective of human health, or as an estimate of the incremental risk associated with user-defined initial contaminant concentrations.

DTSC has modified the USEPA Vapor Intrusion Model spreadsheets by including California-specific toxicity factors and encourages the use of these spreadsheets for screening evaluations. The spreadsheets themselves can be downloaded from DTSC's website. Information on human exposure factors is in Appendix C. There are DTSC-modified USEPA Vapor Intrusion Models for soil gas and groundwater. DTSC strongly encourages all users of these spreadsheets to review not only this Guidance but also USEPA's User Guide for the spreadsheets before conducting any modeling for vapor intrusion at a site (USEPA, 2003b).

Attenuation Factors for Site-Specific Evaluations

In certain situations, the USEPA Vapor Intrusion Model can yield very low attenuation factors for shallow soil gas contamination, exceeding what is reasonable. DTSC does not anticipate that many sites will have attenuation factors of less than 0.00001 for shallow soil gas. Hence, when using the USEPA Vapor Intrusion Model in site-specific evaluations, particularly for brownfields redevelopment, the attenuation factors can in general be expected to range from 0.001 to 0.00001 depending on the future building design. The use of small attenuation factors, between 0.0001 and 0.00001, should be fully explained and justified. The basis for justifying small attenuation factors at a site should not rely entirely on the volumetric water content of the soil. This parameter can be highly transient, especially under buildings where rainwater can no longer infiltrate the soil.

Existing Building

Site-specific evaluations with the USEPA Vapor Intrusion Model should be conducted using the site data obtained in Step 6. A site-specific evaluation should only be conducted after lateral and vertical delineation of the soil gas contamination and identification of all the chemicals of concern at the site. Table 3 summarizes the input parameters for site-specific USEPA Vapor Intrusion Model evaluations for California and the default input parameters specific for California. Appendix D contains information on the limitations of the USEPA Vapor Intrusion Model and provides the rationale for the selection of default input parameters specific to California. Appendix D should be read before conducting fate and transport modeling with the USEPA Vapor Intrusion Model.

If the size of the contaminant plume is smaller than the size of the existing building, a finite contaminant source can be assumed for modeling purposes. The procedures for the use of

a finite contaminant can be found in Johnson and Ettinger (1991) and USEPA (2003b). If using a finite contaminant source in the vapor intrusion modeling, the contaminant plume must be fully characterized both laterally and vertically. In the finite source model, both the soil gas concentration and the amount of contaminant mass in the subsurface are needed. Hence, the VOC contaminant plume must be characterized with both soil gas samples and soil matrix samples. The soil gas samples will yield the contaminant mass in the pore space of the soil and the soil matrix samples will yield the contaminant mass sorbed to the soil matrix, the mass partitioned into soil water, and mass of the free-phase contaminant liquid. Without sufficient characterization data, DTSC will not entertain the use of the finite contaminant source model to evaluate exposure due to vapor intrusion.

Future Buildings

Making a reasonable prediction for vapor intrusion into future buildings is difficult. Many variables may alter subsurface vapor concentrations and the physical properties of the subsurface in the future, including but not limited to: 1) vapor concentrations in the subsurface may increase, accumulating directly under the foundation of a future building, 2) moisture content of the vadose zone directly under a building may decrease due to the inability of rainwater to infiltrate under the building, and 3) air permeability and moisture content of the subsurface may be altered due to construction activities associated with building construction, thereby altering the subsurface air permeability and significantly increasing the potential for vapor intrusion to indoor air. Additionally, there may be significant variability in the quality of foundation materials as well as the construction quality of future buildings. Some foundations will greatly exceed existing building standards and provide protection from subsurface soil gas intrusion. Other foundations will fail to halt soil gas intrusion. Environmental agencies do not regulate nor have any control over the quality of building materials and construction as a mechanism to alleviate vapor intrusion.

Due to the above-mentioned uncertainties associated with predicting indoor air quality for future buildings, DTSC recommends that modeling approaches for future buildings be sufficiently conservative to protect public health. Accordingly, DTSC recommends that the input parameters in Table 3 be used for future buildings but with slight modification. To make a site-specific evaluation for future buildings, maximum soil gas and groundwater concentrations should be used. Also, an appropriate default value for the soil gas advection rate (Q_{soil}) for future buildings should be used. For small buildings (10 meters by meters), USEPA (2002a) recommends using a soil gas advection rate of 5 liters per minute. DTSC believes that this value is appropriate for California and should be used for future building scenarios. If the future building is larger than 10 meters by 10 meters, the soil gas advection rate should be proportionally increased as a function of building size. Hence, buildings larger than 100 square meters will have, for modeling purposes, soil gas advection rates greater than 5 liters per minute.

If a site-specific screening evaluation indicates a potential risk to indoor receptors, either in existing buildings or in future buildings, the installation of permanent soil gas monitoring points should be considered. The installation of permanent monitoring points can be used to evaluate the long-term behavior of soil gas. In these cases, the temporal data trends would be compared to a concentration threshold that would indicate human health is being potentially impacted. When the concentration threshold is exceeded, indoor air testing would be warranted to evaluate the completeness of the exposure pathway.

Step 8: Indoor Air Sampling Assessment

Collecting indoor air samples to assess the risk from vapor intrusion is a challenge. An indoor air assessment requires more than just good data collection. Attention to detail with an acute understanding of the commonalities and differences between subsurface VOCs and other environmental factors, such as vehicle traffic, ambient pollution sources, and consumer products, is vital. Therefore, Step 8 includes information gathering tools and data collection techniques that focus the investigation on the relationship between the subsurface and the indoor air. Step 8 also outlines the proper use of ambient (outdoor air) samples and other air data to justify that the subsurface is not the contributor to indoor air degradation. Indoor air sampling is typically the last step in a vapor intrusion evaluation because of the complexity in evaluating the data.

Interested parties need to think “outside the box” when collecting, reviewing and interpreting indoor air data. Typically, outside influences are not likely to impact the sampling results in soil gas and groundwater investigations. However, this is not the case for indoor air sampling where lifestyle choices, such as receptor smoking or the use of aerosol consumer products, can influence the sampling results. Furthermore, indoor air assessments are particularly difficult to evaluate when the predicted risk from vapor intrusion is low (less than 100-in-a-million cancer risk). These sites fall into the ‘grey area’ and will only be open to proper interpretation if the subsurface plumes are fully delineated, the conceptual site model is accurate, and buildings are adequately scrutinized prior to indoor air sampling.

When contemplating indoor air sampling to evaluate vapor intrusion, an indoor air sampling workplan should be submitted to DTSC for review and approval. The following text discusses the items which should be included in the workplan.

Site Visit

Prior to preparation of an indoor air sampling workplan, a site visit should be conducted to confirm onsite building use and occupancy to further validate the CSM. If the subsurface investigation has identified residential or commercial buildings offsite as potential areas of concern, a neighborhood visit is important to ensure that all buildings are accounted for and documented on the site map. This information can be added to the CSM, specifying the location of the building, type of building construction, building occupancy use, and type of foundation. Also, the businesses in the surrounding area that could influence the indoor air sampling results should be noted. An aerial photograph of the site and the surrounding area is a good evaluation tool. The aerial photograph can also be used to display the results of the soil gas investigation and the lateral dimensions of the soil gas out to non-detectable concentrations.

Detailed plot maps should be prepared from the information collected during the onsite and neighborhood tour and should be included in the indoor air sampling workplan. The plot maps should include all buildings, area streets, outdoor sample locations, monitoring well locations, soil gas sampling locations, utility corridors, predominant wind direction, and compass orientation. Another helpful piece of information is knowledge regarding other industries in the area that could have potential air releases, such as gasoline stations, factories, dry cleaners, parking lots, and freeways. Information on the types of industry in the neighborhood is used when selecting outdoor sample locations and interpreting the air data. The local air district should be contacted regarding the air permits issued in the surrounding neighborhood. The local air district can also provide data from their nearby

ambient monitoring stations. The ambient air data may be used in the uncertainty analysis, but the ambient data should be used with caution. Details that should be included with the ambient data are: date when the data was collected, the data collection method, the analytical detection limits, the meteorological conditions, and the exact location of the monitoring station in relationship to the site.

Ambient air data that are reported as basin-wide results are not useful when evaluating vapor intrusion. The scope and purpose of the basin-wide data are beyond the scope and purpose of an indoor air study. However, ambient data from the local air district or the Air Resources Board are typically included in the final indoor air data report. When conducting a vapor intrusion investigation, ambient data are not used to subtract or reduce the potential impacts found in the indoor air. Any ambient data are included in the uncertainty analysis discussion of the final indoor air assessment report.

The results of outdoor flux chamber sample analysis collected prior to indoor sampling may be included in the workplan. The flux chamber methods, sample duration, sample location, and detection limits should also be included in the workplan. Flux chamber data can be helpful when interpreting the results of the indoor air assessment and can be used in a qualitative matter in the uncertainty analysis discussion of the risk assessment. For example, an outdoor flux chamber measurement may determine that the open ground is off gassing VOCs.

In the workplan, operating on-site soil vapor extraction (SVE) systems and/or groundwater extraction (GE) systems should be noted. Also, it should be noted if the facility is still in operation. Since air releases from the operation of an SVE or GE system or the ongoing operations of a facility can impact the outdoor air sample results, these potential outside influences may impact risk management decisions.

Utility Corridor Assessment

Utility corridors can act as contaminant migration pathways. Contaminants can migrate long distances within utility corridors, distances longer than predicted with conventional fate and transport models. Utility corridors with migrating contaminants may require immediate remedial action to stop further transport of vapors along this preferential pathway. This section summarizes the basic approach to assessing vapor migration in utility corridors. For more detailed information, see the State of Wisconsin's Guidance Document (2003).

All site investigations should include an evaluation of the utility corridors. If utility corridors are not present, the site evaluation should include this documentation. Facility records should be reviewed to determine if utility corridors are present. Facility records include copies of the utility maps, historical use maps, building "as-built" diagrams, and building construction specifications. If soil gas and groundwater contamination extends offsite, an offsite utility corridor evaluation is warranted. Utility corridor maps from the appropriate municipalities should be collected and reviewed.

If utility corridors are present, the site investigation should document the presence or absence of vapor migration within or along utility corridors by collecting active or passive soil gas samples along the corridors. In some instances where utility corridors are identified as significant pathways for vapor migration, monitoring of the corridors with permanently installed monitoring probes may be necessary. To document that a utility corridor is not a migration pathway for the site, it should be demonstrated that soil gas sampling yielded non-

detectable concentrations of VOCs. The indoor air assessment report should identify those circumstances where contaminant migration along or within utility corridors is of concern but cannot be investigated due to access problems.

Utility corridors should be considered a potential preferential pathway for contaminant migration if any of the following conditions are met:

- Utility corridors intersect contaminated media, including areas of non-aqueous phase liquid (free product).
- Utility corridors provide a direct pathway from contamination to receptors in buildings.
- Utility corridor backfill materials are more permeable than the surrounding native soil.

Utility corridors at sites where the native soil is of lower permeability than backfill materials are of greater concern. If these conditions exist, vapors or free product can migrate within a utility corridor regardless of the depth to groundwater. Vapors could migrate in any direction, while free product may migrate in the downslope direction along a trench. Free product or vapor in a corridor could be carried to buildings that are serviced by or connected to the utility. Figure 3 is a decision tree flow diagram for evaluating utility corridors. If vapors are present in utility corridors, the extent of the contamination should be determined through soil gas sampling. Where contaminated soil gas in utility corridors impinge upon an existing building, an evaluation should be conducted to determine if the soil gas concentrations in the corridors are protective of human health.

If utility corridor sampling is warranted, the corridor should be accurately located at the ground surface by an appropriate locator service. The backfilled material in the utility corridor should be sampled to obtain representative soil gas samples. To accomplish this and to avoid utility damage, the sampling locations should be hand-dug to verify placement of the sampling location within non-native material. Ground penetrating radar can be used to locate utility corridor backfill material. The soil vapor probe should be placed into the hand-dug hole and pushed carefully to an appropriate depth and then sampled pursuant to the procedures in Cal-EPA (2003).

Indoor Air Samples

To obtain an indoor air sample for estimating exposure, sampling locations, times and methodology should be carefully selected. A number of factors may directly influence the concentrations of chemicals in the indoor air. Contaminant concentrations are likely to fluctuate to some extent on a continuous basis, and sampling should be conducted with an understanding of this occurrence. Because of contaminant fluctuations in indoor air, the completion of the Building Survey Form (see Appendix K) will aid in interpreting the indoor air sampling results.

To obtain an estimate of exposure, the indoor air sampling approach should involve multiple sampling events. It is generally recommended that sampling be conducted under conservative conditions during appropriate weather conditions with reasonable indoor air exchange. Indoor air samples are typically collected with all windows closed. If the sampling is occurring in the heat of the summer and the home is not air conditioned, the request to close the windows may not be appropriate.

DTSC recommends the following when preparing the indoor air sampling workplan and collecting indoor air samples.

- 1) Sampling Duration. Sampling events should be conducted to produce average concentrations of the monitored compounds over the anticipated daily exposure duration. For residential receptors, air samples should be collected over a 24-hour period. Air samples should be collected over 8 hours for commercial and industrial receptors and over a typical school day for students. Hence, the flow regulators on sampling canisters must be configured to capture an integrated air sample over the daily exposure duration.
- 2) Number of Sampling Events. One indoor air sampling event cannot be reasonably representative of continuous long-term exposure within a building. Multiple sampling events should be conducted to characterize exposure over the long term. Hence, numerous sampling events may be required within a building before DTSC would consider “no further action” for the exposure pathway. At a minimum, sampling data should be obtained over two seasons; late summer/early autumn and late winter/early spring.
- 3) Number of Sample Locations. The occupied living areas as well as basement areas should be sampled. Samples should be taken in a spatial gradient as identified through building screening. Samplers should be situated in the breathing zone, approximately 3 - 5 feet off the ground and lower if the receptors of concern are children as for a daycare center or school. Samples should be taken in the center of the room. At the very least, it is recommended that sampling points include the VOC infiltration point, which is typically the bathroom and kitchen, and the primary living area. For multi-storied residential buildings, at least one sample should be collected on each floor. When sampling an office building, samples should be taken in each discrete office location. Also, for office buildings, samples should be collected from a point of vapor entry, such as a sump or other enclosed space, to better define the potential route of entry and the maximum concentrations.
- 4) Sampling Equipment. When sampling indoor air, extra sampling canisters and flow regulators should be taken into the field in case the integrity of some of the canisters is compromised or if some flow regulators malfunction.

To compute descriptive statistical estimates for most environmental data, a minimum of eight samples are generally necessary, depending on the coefficient of variation of the data and the underlying statistical distribution of the data. Given the cost of indoor air sampling, it is usually not cost-effective to collect enough samples to compute realistic statistical estimates. Usually, two to three samples are taken in a residence or one sample per office space. Therefore, indoor air risk analysis is nearly always based on a limited data set. In these cases, DTSC recommends that the maximum concentration of each identified chemical of potential concern be used to quantify the human health risks.

Data Quality Objective Process

The scope and objectives of the indoor air sampling should be established before the study is conducted. In planning an indoor air sampling assessment, the primary governing principle should be the RCRA Facility Investigation (RFI) or the CERCLA Remedial Investigation / Feasibility Study (RI/FS). The RFI and RI/FS site investigation and cleanup standards are a general performance standard rather than detailed procedural directives. These performance standards are referred to as the data quality objectives (DQO) process.

The DQO process establishes the scope and objectives of the assessment before indoor air sampling is conducted. The DQOs are qualitative and quantitative statements that:

- Clarify the indoor air study objective.
- Identify the chemicals of concern (COCs).
- Define the type, quantity, and quality of each piece of data collected in the study.
- Define if the sample will provide qualitative or quantitative information.
- Define how each sample will be used to assess if vapors are intruding into buildings.
- Determine the most appropriate locations, sampling method, and sampling duration for data collection.
- Specify the amount of acceptable uncertainty in the sampling results.
- Specify how the data will be used to test the exposure hypothesis.

Additional information on the DQO process can be found in USEPA (1994).

Air Sampling Analytical Methods

When sampling indoor air, the target compounds should be the same compounds identified in the soil gas and groundwater. The goal of indoor air sampling is to measure VOCs at levels low enough to compare to background indoor air levels. Therefore, the samples must be analyzed by methods that can achieve minimum detection limits of at least one part per billion by volume (ppbv) which is equivalent to 1 to 7 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) depending on the molecular weight for each compound. The analytical methods for measuring VOCs in air that are capable of achieving these detection limits are TO-14A (non-polar compounds only) and TO-15 (polar and non-polar compounds). USEPA Method TO-17 may also be used, if appropriate. Typically, USEPA Method TO-14A or TO-15 are used when conducting indoor air sampling. Depending on site conditions, TO-1 or TO-2 may be proposed, which are similar to OSHA sampling methods, but are rarely used for indoor air sampling. Prior to choosing an analytical method, the laboratory should verify that they can achieve the minimum detection limits of the target compounds. To avoid interference with background chemicals not found in the contaminated media of concern, the air analysis should be run using the selective ion mode (SIM). Using the SIM analysis technique will also ensure less bias in the results. In addition, a trip blank should be required to ensure that no cross contamination has occurred in the collection or transport of the samples.

Very volatile compounds, such as vinyl chloride, can display peak broadening or co-elution with other species if the compounds are not delivered to the GC column in a small volume of carrier gas. If vinyl chloride is a chemical of concern, ensure that the laboratory undertakes sufficient effort to specifically quantify the chemical.

Methods for collecting indoor air samples are described below.

- USEPA Method TO-1. Method TO-1 uses Tenax adsorption in the field coupled with VOC analysis by GC/MS. TO-1 involves drawing air through a cartridge containing approximately 1 - 2 grams of Tenax resin. Selected VOCs are trapped on the resin, while other VOCs and most inorganic constituents pass through the cartridge. The cartridge is then transferred to the laboratory. For analysis, the cartridge is placed in a heated chamber and purged with an inert gas, which transfers the VOCs from the cartridge onto a cold trap and subsequently into the GC column. Component

identification is accomplished using a library search algorithm based on the GC retention time and mass spectrometry characteristics. Less sophisticated detectors, such as electron capture or flame-ionization, may be used for certain applications, but their suitability for a given application must be verified by the user. For sampling indoor air, only high resolution GC capillary columns should be used.

- USEPA Method TO-2. TO-2 is similar to TO-1 except that a carbon molecular sieve (CMS) is used rather than Tenax resin. The use of a CMS allows for the capture and analysis of more VOCs than the Tenax resin. For example, vinyl chloride is not captured by Tenax resin but is captured by a CMS. Method TO-2 is suitable for evaluating certain non-polar VOCs that have a boiling point between -15 °C and 120 °C. The analytical detection limit varies with the analyte and detection limits of 0.01 to 1.0 ppbv are achievable with a 20-liter sample.
- Method TO-14A. Air samples are collected in an evacuated stainless steel canister with subsequent analysis by GC. VOCs are concentrated in the laboratory with a cryogenic trap and then revolatilized, separated on a GC column, and passed to one or more detectors for identification and quantification, either by MS, electron capture, or flame-ionization. TO-14A is the best method for broad speciation of unknown trace VOCs in air. Nonetheless, care must be taken in using the sampling canisters, because some VOCs may be adsorbed or decompose through interaction with canister walls, and water may condense on the inside of the sampling canisters under high humidity conditions.
- Method TO-15. TO-15 evaluates both polar and non-polar VOCs. GC/MS is used for identification and quantification of target compounds as collected in an evacuated stainless steel canister. TO-15 establishes method performance criteria for acceptance of data, thus allowing the use of alternate but equivalent sampling and analytical equipment. TO-15 also uses a multisorbent/dry purge technique or equivalent for water management. There are only a couple of disadvantages for the method which include high analytical cost and the need for a highly skilled operator for the analysis.

TO-14A and TO-15 samples are collected using canisters. The laboratory conducting the analysis will usually supply clean, certified canisters with the appropriate flow controller set for the specified sampling duration as a function of the anticipated daily exposure. Proper cleaning of canisters is important, since residual canister contamination can impact both detection limits and the reproducibility of results. Instructions for using the flow regulator should be obtained from the canister supplier or laboratory.

In most cases, TO-14A or TO-15 will be used for indoor air sampling. The laboratory detection limit for Method TO-14A is 0.2 ppbv. Lower detection limits are possible with Method TO-15. Caution is needed when selecting the sampling method since high levels of VOCs in indoor air can overwhelm the GC/MS and damage the detector. If high concentrations of VOCs are anticipated, TO-14A should be used first, and if necessary, followed-up with TO-15 if lower detection limits are needed.

For petroleum release sites, specific indicator compounds within petroleum should be evaluated for vapor intrusion exposure. Petroleum is a mixture of many individual compounds. Petroleum products, such as gasoline, diesel, fuel oil, and mineral spirits, have different chemical constituents and specific aromatic and aliphatic compounds. Analytical methods using a mass spectrometer detector allow for the identification of aromatic and

aliphatic hydrocarbons, polynuclear aromatic hydrocarbons, and oxygenated compounds such as ethanol, acetone and methyl tertiary butyl ether (MTBE).

The discrete samples collected in most indoor air investigations may not adequately address temporal variation in the data. It is usually not possible to collect enough samples to do a rigorous statistical evaluation of long term average concentrations. As such, even using average concentrations collected in one or two days of sampling may not be reflective of long term average exposure levels used to evaluate health risks. For this guidance DTSC recommends that risks be estimated using maximum concentrations, or one-half the detection limit when a chemical of potential concern is expected to be present based on site characteristics, but which may not have been detected due to elevated detection limits for some types of air sample analyses.

Contingency Planning

Indoor air sampling data will be used to identify further activities or responses to better ascertain human health impacts and their associated mitigation measures. The need for specific responses will be determined on a case-by-case basis, depending on the data from the two indoor air sampling events. Hence, for the indoor air sampling workplan, a contingency plan is prepared prior to initiating indoor air sampling and included as part of the sampling plan. The following is a general outline of responses subsequent to collecting and evaluating indoor air sampling data; however, there is a range of potential responses that can be considered.

Indoor Air Sampling Results (minimum of two indoor air sampling events needed)	Response	Activities
Risk: <10 ⁻⁶ HI: <1.0	Minimal	Determine that the soil vapor plume is stable.
Risk: 10 ⁻⁴ to 10 ⁻⁶ HI: 1.0 to 3.0	Monitoring	Install permanent subslab monitoring points and/or permanent vadose zone monitoring points and collect soil gas samples and indoor air samples semi-annually.
Risk: >10 ⁻⁴ HI: >3.0	Mitigation	Institute engineering controls to mitigate exposure and collect soil gas samples and indoor air samples semi-annually to verify mitigation of exposure.

HI = hazard index – sum of hazard quotients of specific chemicals found in indoor air

The above table is provided as guidance and is not meant to circumvent the Superfund regulatory process of the nine feasibility study criteria pursuant to Title 40, Federal Code of Regulations, Section 300.430. All response actions associated with indoor air sampling should be done in consultation with DTSC or the lead regulatory agency.

Indoor Air Sampling Workplan

The indoor air sampling workplan, which should be submitted to DTSC for review and approval, should include the following:

- History of the site.
- Results of site visit (inventory of onsite and offsite buildings).
- Conceptual site model.
- Utility corridor assessment.
- Number and type of air sample collection.
- Duration of the air sample collection.
- Laboratory analytical methods.
- Contingency plan.

After approval of the indoor air sampling workplan by DTSC, the occupants of the buildings potentially subject to vapor intrusion are contacted and indoor air sampling takes place.

Step 9: Indoor Air Sampling

Indoor air sampling may require four visits to the building subject to vapor intrusion. The first visit is the pre-sampling interview with the occupants, the second and third visits are during the placement and retrieval of the air sampling equipment, and the fourth visit is to discuss the results of the indoor air sampling with the building occupants. A representative of DTSC should be present during all visits, and sampling technicians are advised to conduct indoor air sampling in pairs. DTSC's public participation unit can assist with planning and conducting sampling visits.

Prior to the pre-sampling interview, an initial contact with the building occupants through telephone interviews is conducted. Residents should be contacted approximately 30 days prior to the indoor air sampling event. The purpose of the phone contact is to provide an overview of the history of the project, the intent of the indoor air assessment, and to invite the occupants to participate in the investigation.

Voluntary participation and an individual's right to privacy are very important when conducting indoor air sampling. To ensure that the privacy of each building occupant is protected, all indoor air sampling information is kept confidential. The confidentiality of the data should be communicated to the building occupant at the time of the phone interview. Appointments are scheduled at the convenience of the building occupant. Therefore, it is not uncommon to schedule appointments and sampling in the evening after people return home from work.

A pre-sampling interview should be conducted for each building. During this site visit, the Building Survey Form should be completed (see Appendix K) and a screening of the building should be conducted. A floor diagram should be generated, illustrating the floor layout, chemical storage areas, garages, doorways, stairways, basement sumps, plumbing, electrical conduits, elevator shafts, and any other pertinent information (New York, 2001). Compass direction should be included on the floor diagram.

Upon deployment of the sampling equipment on the second site visit, the Building Survey Form is updated to include the location of the sampling equipment, time, date, identification number, and environmental conditions. At this time, it is important to ensure that no changes to the condition of the building have taken place since the first visit and that no consumer products are left open. A photograph of each sampler should be taken with the identification tag and pressure gauge visible. A second photograph and notes are taken when the sampling equipment is collected. Any changes in the environment should be noted and the occupant(s) asked if any consumer products were used or if there were any activities (such as smoking) that may have taken place during the time the sampling equipment was in the building.

The laboratory reports for the indoor air sampling should be communicated to the building occupants. The results should be initially communicated verbally over the telephone to the occupants with another site visit shortly thereafter to explain the results directly. The final written report associated with indoor air assessment should be made available to all building occupants. If needed, a public workshop or forum should be convened to communicate the testing results to the community along with the associated mitigation measures. DTSC recommends that public meetings be held after each indoor sampling event. Ideas and suggestions for holding public workshops or forums are provided in the Public Participation Section.

Building Screening for Preferential Pathways

A preferential pathway is a crack or opening in the building foundation which may allow for the flow of subsurface vapors into the indoor air space. An opening in the building foundation can be located at the foundation-wall joints, around where plumbing, electrical, or sewer lines enter the building from the subsurface, at elevator shafts, floor drains, or around bathtubs and showers. Likewise, vapors may enter a building through foundation cracks and along concrete control joints in the foundation.

Vapors migrate from the subsurface due to changes in pressure with the building. The rate at which air enters a building is a function of several factors including wind speed, indoor-outdoor temperature differences, barometric pressure changes, height of the building, leaks in the building shell, and ventilation equipment such as bathroom and kitchen fans, furnaces and fireplaces. Although these pressure differences are small, typically between 1 and 10 pascals, this slight depressurization can cause the migration of soil gases through cracks and openings in the building's foundation to indoor air spaces (USEPA, 1992a, 1992b). Figure 2 shows conceptually how subsurface vapors migrate into buildings.

During the pre-sampling interview, an evaluation of the preferential flow pathways and the ventilation system should be conducted. Problems with the building ventilation system may in some cases exacerbate what would otherwise be relatively minor vapor intrusion concern. VOC readings from the preferential pathways should be recorded using an appropriate field instrument. Selection of the field instrument should be based on the anticipated VOC concentrations entering into the buildings. If contaminants in soil gas or slab samples were found at high concentrations, then field measurements can be conducted with a photo-ionizing detector (PID) or a flame-ionizing detector (FID), since the anticipated indoor air concentrations would exceed the analytical detection limits of these instruments, which is approximately one part per million by volume. If the anticipated indoor air concentrations are low, then a field portable gas chromatography/mass spectrometry (GC/MS) instrument may be used to evaluate the preferential pathways. This instrument requires a trained

operator but provides instantaneous indoor air results. The standard operating procedures (SOP) for the instrument should be included, along with its detection limits, in the indoor air sampling workplan.

The field GC/MS may be run in MS mode to gather qualitative information about the suspected chemicals of concern. Unlike a PID or FID, the field GC/MS in MS mode can qualitatively identify the presence of a specific chemical. For a quantitative evaluation, the field portable GC/MS must be run in GC/MS mode. To shorten the run time and ensure that the instrument detects only those chemicals known to be in the subsurface, the GC/MS should be run in the selective ion mode.

All measurements collected with the portable field equipment should be recorded, annotated on building plot plans, and included in indoor assessment reports.

Building Screening for Consumer Products

Field instruments can be used to evaluate contaminant sources that might degrade indoor air quality unrelated to vapor intrusion, such as chemicals in common consumer products, which might bias indoor air sample collection. During the pre-sampling site visit, these sources can be identified and either sealed or removed prior to indoor air sampling. It is important to identify and mitigate the consumer products as contaminant sources prior to collecting indoor air samples with Summa™ canisters, so the analytical results can be interpreted without this confounding factor. Removing these interfering sources from the indoor environment prior to testing is the most effective means of reducing such interference. Sealing containers may be acceptable, but the containers should be tested with a field instrument to demonstrate that the seal is tight. The inability to eliminate potentially interfering substances may be justification for not sampling. Once these interfering conditions are corrected, ventilation may be needed before sampling to eliminate residual contamination (New York, 2001).

Commercial and household products in buildings should be inventoried every time air is tested to provide an accurate assessment of their potential contribution to indoor air VOCs. Each room in the building should be inspected, and products that contain VOCs should be listed on the Household Products Inventory Form (Appendix L) along with the field instrument readings obtained near the containers. The volatile ingredients should be recorded for each product. If the ingredients are not listed on the label, the manufacturer's name, address, and phone number, if available, should be recorded. It is not uncommon for indoor air sampling to show trace levels of these VOCs. Since the recommended TO-14A and TO-15 sampling methods can achieve detection limits down to 0.01 micrograms per liter, off-gassing of normal household items, such as household cleaners, glues, fingernail polish remover, aerosol sprays, carpeting, paint, recently dry-cleaned clothes, and tap water can interfere with the results.

Indoor Air Sampling

Indoor air sampling should be done in an environment that is representative of normal building use. Heating and air conditioning systems should be operated normally for the season and time of day. Weekend sampling, when buildings are shut and not occupied, is not recommended and may bias the results low, since the heating and air conditioning systems may depressurize the building relative to the subsurface.

Any ventilation should be conducted twenty-four hours or more prior to the scheduled sampling time. If ventilation is necessary, windows and doors should be opened for at least 10 to 15 minutes. During colder months, heating systems should be operating for at least twenty-four hours prior to the scheduled sampling time to maintain normal indoor temperatures above 65 °F before and during sampling.

The following should be recorded 24 hours prior to sampling:

- Any open windows, fireplace dampers, openings or vents (this may be difficult in office or school environments).
- The operation of ventilation fans.
- Smoke (note distance to outdoor smoking area from building entrance).
- Type of kitchen stove/oven (gas or electric).
- Fresh paint.
- Use of wood stove, fireplace or other auxiliary heating equipment, (e.g. kerosene heaters).
- Operation or storage of cars in attached garage; for offices/businesses, the distance from the entrance to parking lot or street.

The following should not be permitted during the sampling event:

- Allowing containers of gasoline or oil within the building or garage area, except for fuel oil tanks.
- Cleaning, waxing or polishing of furniture or floors (if cleaning is needed, use water only).
- Using air fresheners or odor eliminators.
- Using materials containing VOCs (dry markers, white out, glues, etc.).
- Using cosmetics including hairspray, nail polish, nail polish removers, perfume, and cologne.
- Applying pesticides.

Ambient (Outdoor) Air Samples

When an indoor air assessment is conducted, ambient air data (outdoor samples) should also be collected. Since the focus of the indoor air assessment is on collecting data specific to the soil or groundwater contamination, the ambient air sample should be evaluated in the same manner. The ambient air data can be used as a qualitative tool to provide information on outside influences on indoor air quality. In addition, ambient air samples provide quality control information about the collection and analysis techniques used. Ambient air sampling may help determine whether the laboratory is able to detect low ambient levels of target VOCs or whether sample contamination or other problems have contributed to unusual results.

For measuring ambient air, DTSC recommends that ambient sampling begin at least one hour, and preferably two hours, before the indoor air sampling begins. This is recommended since most buildings have an air exchange rate of 0.5 - 1.0 exchanges per hour and, thus, ambient air enters the building before indoor air sampling begins. The ambient air sample should be collected until at least 30 minutes prior to the end of the indoor sampling period.

The ambient air sample should be in an upwind location on the upwind side of the building. The sampling equipment should be located away from gasoline stations, automobiles, gasoline-powered engines, oil storage tanks, industrial facilities, or dry cleaners. The sampler should not be hung on vegetation but be placed away from wind breaks, such as trees or bushes. The sampling equipment should be at least five feet off the ground, at the approximate midpoint of the ground story level of the building, and about 5 to 15 feet away from the building.

The focus of the indoor air sampling evaluation should be on the specific chemicals identified in the soil gas or groundwater. The justification for this focus is:

- Control strategies are designed to prevent subsurface contaminants from entering the building. Chemicals present in the building that are not known to be in the subsurface, but are risk drivers, will not be reduced when remedial controls are implemented.
- The objective of the indoor air sampling investigation is to determine if the contamination underneath the building is entering the indoor environment.
- Background (ambient) samples should only be used to determine if the same chemicals of concern are also present in ambient air and could be contributing to the concentrations indoors.
- If the chemicals of concern in indoor air are also present in ambient air, the outdoor data is qualitative.
- If outdoor or indoor samples comes back from the laboratory with all non-detectable concentrations, the data should be rejected and the samples should be reanalyzed. Ambient air in California contains numerous VOCs, and these VOCs, such as benzene and tetrachloroethylene, should be found in both outdoor and indoor air, regardless of the occurrence of vapor intrusion. However, vinyl chloride and daughter products from the breakdown of chlorinated solvents, such as 1,1-dichloroethylene and cis-1,2-dichloroethylene, are NOT typically found in ambient air.

Under no circumstances should indoor air samples be collected in a building not subject to vapor intrusion as a way to evaluate background concentrations. Indoor air concentrations can vary greatly between buildings even if each building is used for similar purposes. DTSC believes that using a building as a “control” is unreliable.

Quality Assurance/Quality Control

Only certified clean sampling devices should be used for air sampling. Precautions should be taken to avoid sample interference such as fueling vehicles prior to sampling or using permanent marking pens in the field. A trip blank is required to ensure that there are no impacts from these types of sources that could affect the results of the study. Once the samples are collected, they should be stored according to the method protocol and delivered to the analytical laboratory as soon as possible. Samples should not exceed recommended holding times prior to being processed by the laboratory. Field blanks should be submitted and analyzed with the samples to provide a quality check. Laboratory procedures for sample accession and chain-of-custody should be followed.

Step 10: Evaluation of Indoor Air Sampling Results

DTSC recommends a minimum of two indoor air sampling events before making a final risk determination for a site. One sampling event should occur in the late summer/early fall and another during late winter/early spring. The maximum measured indoor air concentration of a specific chemical should be entered into the equations given in Appendix C of this guidance in order to calculate the risk or hazard posed by that chemical for vapor intrusion. Alternatively, the indoor air concentrations can be compared to the OEHHA target indoor air concentrations. The risks from all target VOCs should be added together to obtain the total risk for the indoor air exposure pathway. Any site-specific exposure evaluation that deviates from the assumption of residential land use should be performed only with the approval of the DTSC. DTSC stresses that the inhalation of indoor air contaminated with VOCs intruding from the subsurface is only one of many exposure pathways that are evaluated in a human health risk assessment. Hence, the risk or hazard from this pathway is added to the risks/hazards posed by all other chemicals and all other potentially complete exposure pathways, in order to calculate the total or cumulative risk at a site, as discussed in other USEPA guidance (USEPA, 1989).

The background or ambient sample results should be included and discussed in the uncertainty analysis section when reporting sampling results.

Response Action and Contingency Planning

Indoor air sampling data should be used to identify further activities or responses to better ascertain human health impacts and their associated mitigation measures. The need for specific responses will be determined on a case-by-case basis, depending on the data from the two indoor air sampling events. The response action for the site should follow the contingency plan as provided and approved by DTSC in the indoor air sampling workplan.

All response actions associated with indoor air sampling should be done in consultation with DTSC or the lead regulatory agency.

Step 11: Mitigate Indoor Air Exposure, Monitoring, and Implementation of Engineering Controls

DTSC considers four remedies to be common for the mitigation of vapor intrusion. Three criteria were used to select the recommended mitigation measures: effectiveness, implementability, and cost. Other remedies may be proposed for DTSC review and approval.

These remedies may be used to mitigate vapor intrusion but additional measures may be warranted, such as soil gas monitoring, subsurface vapor extraction, sensors, alarms, conduit seals, slab crack sealing, utility trench dams, and enhanced ventilation systems. While specific remedies are not discussed here for sites where vapor intrusion yields low indoor air VOC concentrations, a combination of enhanced interior ventilation systems, conduit seals, utility trench dams, and other easily installed improvements should be considered for these types of scenarios.

All design, construction, operation, and maintenance activities associated with vapor intrusion remedies should be conducted and supervised by a California Registered Civil Engineer with DTSC oversight and inspection. When implementing these remedies, one

must follow the California Energy Code (Title 24) for weatherization, which could result in additional energy savings and lower utility bills, as well as reduced VOC concentrations inside a building.

Mitigation Measures

The four remedies are discussed below.

I. Excavation of VOC Sources

The excavation and disposal of VOC contaminated media is a viable remedy to mitigate vapor intrusion. Excavation can be a permanent solution for alleviating threats to human health and the environment. All excavations should be backfilled with clean fill material pursuant to DTSC (2001a). The presence of additional sources and the onsite migration of VOCs from offsite sources should be considered when contemplating this alternative.

Soil excavation at a site should be considered only when VOC contamination is shallow, usually less than 15 feet below grade, does not extend under buildings, and when the contamination is limited in extent, usually less than 500 cubic yards in volume. For larger contaminated areas, other remedial methods besides excavation, such as soil vapor extraction and in-situ chemical oxidation, may reduce the VOC contamination to levels protective of indoor air quality.

If a consent order or an Operation and Maintenance (O&M) agreement is developed for the excavation, typical activities that may be required include:

- 1) Collection of confirmation soil samples in the excavation pit to verify removal of all contaminated material.
- 2) Sweeps of the ground surface with a field instrument to monitor for the occurrence of VOCs.
- 3) Installation and routine monitoring of soil gas probes in the excavation area to verify mitigation of the soil gas plume.

II. Existing Building Retrofit - VOC Collection and Passive Vent Systems (Without Membrane)

The installation of a subslab soil gas venting system can mitigate vapor intrusion into existing buildings. This mitigative approach involves the installation of a subslab collection system with either a passive or active venting system in existing structures where installation of a membrane system below the foundation is not feasible. These types of systems have been used in the past to mitigate the intrusion of radon into buildings.

The following items should be considered when designing a subslab venting system:

- 1) Collection Pipe Spacing. A collection pipe system for VOC capture should be installed immediately beneath or adjacent to the foundation slab. The number and spacing of collection points should be based upon the soil and engineered fill properties underneath the building. The diameter of the piping should be appropriate for the capacity of the collection system.

- 2) **Collection Pipe Layout.** The gas collection piping should be installed either horizontally or vertically beneath the building. Horizontal collection piping is usually installed along the perimeter of the building with horizontal drilling techniques, with the piping physically extending under the building. Vertical collection piping is installed within the interior of the building with vertical drilling techniques. Care should be taken on installation of the collection system so that building footings and utility corridors are avoided. The collection pipe system should be connected using threads, rather than connected with glues or solvents. The need for drainage or de-watering improvements to prevent flooding of any portion of the collection piping should be evaluated and suitable improvements should be contemplated, as necessary, to insure the proper operation of the collection pipe system.
- 3) **Vent Riser Design.** The underground gas collection pipes should be connected to solid vent risers that extend above the building. The vent risers should be equipped with a sampling port and fitted with a non-restricting rainguard to prevent precipitation and debris from entering the piping system. Vent risers should be properly secured to the building for protection against damage. Vent risers should terminate at a minimum of two feet above the roof of the structure and be a minimum of 10 feet away from any window or air intake into the building. The diameter of the vent riser should be appropriate for the capacity of the system. A small fan or blower within the vent riser may be required. If a fan or blower is warranted for the system, the installation of a utility trench to the riser may be necessary for the connection to electrical power.
- 4) **Utility Conduit Seals.** Conduit seals should be provided at the termination of all utility conduits to reduce the potential for gas migration along the conduit to the interior of the building. These seals should be constructed of closed cell polyurethane foam, or other inert gas-impermeable material, extending a minimum of six conduit diameters or six inches, whichever is greater, into the conduit. Wye seals should not be used for main electrical feed lines.
- 5) **Air Discharge Permits.** Permits or authorizations from the local air pollution control district (APCD) or air quality management district (AQMD) may be required for venting systems that exhaust to atmosphere. DTSC recommends that the local APCD or AQMD be consulted to confirm their requirements.

III. Future Building Construction - VOC Collection, Membrane, and Passive Vent Systems

This remedy for new buildings involves the installation of a passive subslab VOC collection and vent piping, and a membrane system underneath the foundation. All considerations for the existing structure retrofit remedy described above are applicable for this mitigation measure, except for the following:

- 1) If an appropriate permeable engineered material is needed for the collection piping (e.g., sand or gravel), the evaluation of native soil characteristics may not be necessary for the pipe spacing design.
- 2) Gas Barrier/Membrane System should meet the following requirements:
 - a. Gas membranes should be constructed of appropriate materials and thicknesses.

- b. Gas membranes should be placed a maximum of one foot below the foundation slab and a maximum of six inches above the gas collection piping.
- c. Protective layers consisting of at least two inches or more of sand and/or geotextile (six ounces per square yard at a minimum) should be laid below and above the membrane.
- d. Without an engineering evaluation and confirmation data to support the beneath footing passage, the membrane should not pass below footings and/or stiffener beams of the structure due to seismic concerns.
- e. Gas tight seals (e.g., boots) should be provided at all pipe or conduit penetrations through the membrane. Gas tight seals should be provided where the membrane attaches to interior and perimeter footings.
- f. A smoke test of the membrane system (as recommended by the membrane manufacturer) should be conducted to ensure no leaks exist. Where leaks are identified, appropriate repairs should be undertaken and smoke testing should be repeated until no leaks are detected.

IV. Future Building Construction - VOC Collection, Membrane, and Active Vent Systems

In some situations, newly constructed buildings will require active subsurface venting to alleviate vapor intrusion. In this remedy, all considerations for the existing structure retrofit remedy specified above are applicable; however, a properly sized blower will need to be included in the design. An air permit from the local APCD or AQMD is typically required for an active venting system, and it is advisable to consult with the APCD or AQMD for permit requirements. The additional considerations for an actively vented building are:

- 1) Active Injection of Air Under Buildings. Active injection of air under a building to enhance venting is not recommended without an engineering design. The air injection system may force vapors into a building by creating elevated subsurface pressures or force vapors into unprotected neighboring structures. Although an air permit from the local APCD or AQMD is typically not required for an active injection of air system, it is advisable to consult with the APCD or AQMD.
- 2) Lower Explosive Limit of Chemicals. For sites where subsurface concentrations are above the lower explosive limit (LEL) of any constituent and a subsurface gas pressure of one psi or more is present, the site should be carefully evaluated and a deep well pressure relief system or other improvements, which reduce or eliminate subsurface gas levels and pressures, should be considered in addition to the building protection system. Mitigation of the elevated gas pressures at these sites may be required as a condition of site approval.

The selection of the style of venting, either active or passive, is based on the level of mitigation needed to prevent vapor intrusion. The need to actively vent a building should

consider the level of protection needed, the type of receptor being exposed (residential, commercial or industrial), and the duration of the potential exposure. If there is uncertainty that passive venting of a building will satisfactorily protect receptors, active venting should be undertaken.

Operation and Monitoring (O&M) Requirements for Venting Systems

Typical O&M activities for the mitigation of vapor intrusion by either passive or active venting systems may include the following:

1. A one-time initial indoor air testing of all newly vented buildings to determine if the mitigative remedies are functional and operating according to design specifications.
2. Routine inspection of the area of concern, including all visible components of the VOC venting systems and the multi-level gas probes, to ensure there are no significant changes in site condition and there are no signs of degradation of the VOC remedy components.
3. Routine monitoring of air, lowest accessible floor and enclosed areas of the structures of concern, and grade surface areas, to ensure there are no potentially significant changes in subsurface gas concentrations.
4. Routine monitoring of vent risers for flow rates and gas concentrations to confirm that the VOC venting systems are functioning properly.
5. Routine maintenance, calibration, and testing of functioning components of the VOC venting systems in accordance with the manufacturers' specifications.

Permanent Soil Gas Monitoring Points

The installation of permanent soil gas monitoring points should be considered when the subsurface soil gas concentrations approach values that are not protective of human health. The installation of permanent monitoring points can be used to evaluate the long-term behavior of soil gas adjacent to existing or future buildings. In these cases, the temporal data trends would be compared to a concentration threshold that would indicate human health is being potentially impacted. When the concentration threshold is exceeded, indoor air testing would be warranted to evaluate the completeness of the exposure pathway.

When a soil gas monitoring program is proposed, a detailed outline for the program should be prepared and submitted to DTSC for review and approval. The outline should specify monitoring procedures, locations, frequencies, and equipment. A contingency plan should also be provided along with a description of the conditions at which the contingency plan would be implemented. The design of the VOC monitoring program should incorporate the following considerations:

- 1) Monitoring by subsurface gas probes should include the measurement of the concentrations of VOC by TO-14A, methane, oxygen, and carbon dioxide as well as the measurement of the gas pressure within the probe and the barometric pressure at the time of the monitoring. For oil field sites, landfills, or other sites where the presence of hydrogen sulfide is suspected, analysis of hydrogen sulfide should also be included.

- 2) Periodic monitoring of combustible gas levels along the ground surface in open areas, within crawl spaces beneath a structure, and in indoor air may also be included as part of this program.
- 3) All gas probes should be properly secured, capped and completed to prevent infiltration of water and ambient air into the subsurface and to prevent accidental damage or vandalism of the probes. Replacement or repair may be needed due to the conditions of the gas probes or disturbance due to construction activities. For probe surface completions, the following components should be installed:
 - a. Surface seal.
 - b. Utility vault or meter box with ventilation holes and lock.
 - c. Gas-tight valve or fitting for capping the sampling tube.
- 4) Changes in subsurface conditions may warrant the re-evaluation of the soil gas conditions at the site. Sites that potentially have VOC soil gas contamination associated with the biodegradation of organic material entrained within the soil may require reassessment of soil and soil gas conditions after completion of the grading activities for construction purposes. This is because the distribution of the organic material, oxygen and soil moisture may be altered by the grading activities. The placement of fill containing elevated levels of organic matter can result in higher post-grading VOC concentration levels.
- 5) Surface paving and building construction can alter the movement of VOCs in the subsurface. For buildings subject to vapor intrusion, nearby construction activities can affect the potential for vapor intrusion. Oftentimes the building becomes the easiest vent point because trenches and pipes installed below the building provide a relief point. Therefore, the installation of hard-scraped areas covering 5,000 square feet or more within fifteen feet of any structure of concern may require the installation of VOC mitigation measures such as vent trenches and vent piping, in addition to a soil gas monitoring program, to protect the structure.

Perimeter Monitoring at a Facility

The installation and routine monitoring of perimeter soil gas probes may be required to evaluate the potential for VOC migration during the venting of buildings. The perimeter soil gas monitoring system should include a network of multi-level soil gas monitoring probes, evenly spaced at approximately 1,000 feet apart, with a minimum of four locations, along the perimeter of the site, between the property boundary and the membrane system. The multi-level sampling probes should be installed approximately 5 and 15 feet below grade depending upon the site geology, depth of fill material, and depth of groundwater.

Institutional Controls and Deed Restrictions

When the removal of all volatile chemicals from the subsurface is not possible, institutional controls with their prescribed notifications, prohibitions, and engineering controls must be utilized to prevent exposure due to vapor intrusion. If existing conditions may cause unacceptable future risk to receptors, effective legal notification to future buyers of the property, occupants of future developments, or re-developments on the property will be required. In this case, it is appropriate to record in the property deed for the site: 1) a notice of the existing conditions known to the environmental agency that may cause potential

unacceptable risk from vapor intrusion or other exposure pathways, 2) a prohibition against construction without approved removal or treatment of contamination to approved risk-based levels, and 3) the implementation and monitoring of appropriate engineered remedies to prevent indoor air contamination until specific risk-based environmental cleanup levels have been met. This documentation should clearly name the regulatory agency responsible for the oversight and enforcement of the institutional controls. Deed restrictions should be approved by DTSC legal counsel and publicly recorded in the County Records Office. DTSC has approved standard Model Deed Restrictions that will reduce the work burden for all parties involved in this effort. Additionally, deed restrictions or land use covenants must include the requirement to notify utility workers or contractors that during utility installation or construction activities, these workers may contact contaminated soil and ground water.

BIODEGRADATION OF VOLATILE PETROLEUM HYDROCARBONS

Aerobic biodegradation of petroleum hydrocarbons will occur in the vadose zone if proper conditions exist in the subsurface. If sufficient oxygen and indigenous microbes exist along with the occurrence of appropriate soil moisture, nutrients, pH conditions, and salinity, petroleum hydrocarbons can readily biodegrade in the vadose zone. While conditions conducive to biodegradation usually exist within the vadose zone, exceptions occur in California which preclude the adoption of a policy by DTSC that petroleum hydrocarbons always biodegrade in the vadose zone, posing no vapor intrusion risk. Therefore, petroleum hydrocarbons at sites in California must be evaluated for the possibility of vapor intrusion.

To evaluate the vapor intrusion of petroleum hydrocarbons, subsurface contamination should be delineated by the collection of soil gas samples. Soil gas samples should be analyzed for the appropriate chemical indicators within the petroleum hydrocarbon mixture. These indicator compounds are usually benzene, ethyl benzene, toluene, xylene (BTEX), naphthalene, polynuclear aromatic hydrocarbons (PAHs) and fuel oxygenates, dependent upon the composition of the petroleum hydrocarbons. Likewise, the soil gas samples should also be analyzed for any biodegradation byproducts which may pose a health risk. (See Table 1 for chemicals to be considered for analysis.)

Aerobic biodegradation of petroleum hydrocarbons will result in the consumption of oxygen and generation of carbon dioxide. These two geochemical indicator chemicals of aerobic biodegradation should be included in the soil gas sampling, to assess the potential for bioattenuation of subsurface petroleum vapors.

To evaluate bioattenuation of volatile petroleum hydrocarbons in the subsurface, the measured vapor concentrations with depth should be compared with the theorized vertical concentration profile. This can be done using the procedures in Johnson et al. (1998). If there is good agreement between the observed vertical contaminant profile and the theorized diffusional contaminant profile, biodegradation is not playing a significant role in vapor transport. However, the comparison of observed contaminant profiles with theorized profiles should only be done if the site has reached steady-state conditions. Steady-state conditions can be inferred to exist at site if the petroleum release is at least three years old and the contaminant concentrations in groundwater have stable or decreasing trends. Otherwise, the soil gas and groundwater plumes will be inferred to be expanding and the documentation of bioattenuation will not be possible. Hence, to effectively document the occurrence of bioattenuation, the installation and monitoring of permanent vadose zone monitoring points may be warranted.

If there is disagreement between the observed vertical contaminant profile and the theorized diffusional contaminant profile, biodegradation of the petroleum hydrocarbon may be occurring in the subsurface. The occurrence of biodegradation can be evaluated with the oxygen and carbon dioxide data. When biodegradation occurs, the oxygen content of the vadose zone and the petroleum vapor concentration should sharply decrease and the carbon dioxide content should have an associated increase. In plotting the vapor, oxygen, and carbon dioxide concentrations with depth, it should be obvious that a zone exists in the subsurface where substantial changes in the concentration profiles occur. This area of concentration change, for the vapor, oxygen, and carbon dioxide, is the “zone of biodegradation”. If there is not a clear correlation in vapor, oxygen, and carbon dioxide profiles, biodegradation may not be occurring at the site and the unique contaminant profile with depth is attributable to an alternate cause.

In evaluating sites for vapor intrusion, the “zone of biodegradation” in the subsurface must exist at sufficient depths below the surface so that anthropomorphic activities are unable to disturb the zone. If future development activities at a site can potentially affect the “zone of biodegradation,” DTSC will consider that the zone does not exist at the site for the evaluation of vapor intrusion. Activities that might affect the “zone of biodegradation” include, but are not limited to, removal of the zone for building construction, alteration of subsurface moisture conditions and the disruption of atmospheric oxygen migration by the placement of buildings and pavement at the surface.

CONFIRMATION SAMPLING FOR THE COMPLETION OF REMEDIATION

Remediation of VOC contamination may be warranted at some sites. Some of the approaches for the cleanup of subsurface VOC contamination are excavation, soil vapor extraction, and in-situ chemical oxidation. To verify that cleanup activities have reduced the subsurface VOC concentrations to levels protective of human health, including receptors subject to vapor intrusion, confirmation soil gas samples should be collected and analyzed for appropriate constituents of concern. For sites treated by in-situ chemical oxidation, the soil gas should also be tested for byproducts of the oxidation process. Soil gas samples should be collected using the procedures within DTSC’s Soil Gas Advisory (2003), and the density of sample collection should be appropriate to verify contaminant removal.

Confirmation soil gas sampling after the completion of soil vapor extraction should take place after steady-state conditions are reached in the subsurface, which usually occurs within 12 to 16 months after system shutdown.

REPORTING OF VAPOR INTRUSION

DTSC anticipates that two documents will be submitted for agency review and approval during the process of evaluating a site for vapor intrusion. Prior to the initiation of any activities in the evaluation of vapor intrusion, workplans must be submitted to DTSC for review and approval. Workplans should be submitted for all phases of work, such as site characterization of subsurface contamination, evaluation of indoor air exposure through modeling, sampling for indoor air quality, sampling for long-term monitoring, and implementation of engineering controls. Likewise, reports describing the completion of all these activities, along with interpretations and conclusions derived from the data, should also be submitted to DTSC for approval.

The following items should be included in a vapor intrusion risk assessment report that is submitted to DTSC:

- 1) Conceptual Site Model (CSM). The CSM should describe site conditions and state the assumptions made to generate the CSM. The CSM should describe the potential for exposure to hazardous contaminants based on the sources of contamination, the release mechanisms, the transport media, the exposure pathways, and the potential receptors. The CSM should include a diagrammatic or schematic presentation that relates the source of contamination to human receptors and identifies all the potential sources of contamination, the potentially contaminated media, and exposure pathways.
- 2) Laboratory Reports. All laboratory reports associated with environmental analyses, both analytical and geotechnical, should be submitted. The laboratory reports should include all the quality assurance and quality control information, such as the analytical method(s) used, laboratory control samples, matrix spikes, matrix spike duplicates, field duplicates, trip blanks, and equipments blanks. Additionally, the analytical detection limits should be annotated in the laboratory reports and the detection limits should be sufficiently low so that vapor intrusion evaluations can be properly conducted.
- 3) Maps of Contaminant Distribution. Plume maps should be provided with the spatial distribution of contaminants in the subsurface. The maps should display the contaminant distribution, both for soil gas and groundwater, through the depiction of isoconcentration contour maps for the constituents of concern. All data used to construct the contour maps should be clearly annotated on the maps. Ideally, the base map for plume presentation should be provided on an aerial photograph.
- 4) Modeling Input Parameters. All the input parameters used for vapor intrusion modeling should be provided, along with the technical justification for their selection. All the input parameters should be summarized into a single table.
- 5) Vapor Intrusion Modeling Results. The computational method used to quantify the risk associated vapor intrusion should be provided. If the USEPA Vapor Intrusion Model is used, copies of the EXCEL™ spreadsheets should be included.
- 6) Model Sensitivity Analysis. To understand the effect of the input parameters on the indoor air risk, a sensitivity analysis should be performed. The input parameters that should be evaluated, at a minimum, are soil volumetric water content, soil volumetric air content, total porosity, air permeability, indoor air exchange rate, and indoor-outdoor pressure differential. DTSC recommends that the sensitivity analysis be conducted in a similar manner to that described by Johnson (2002).

To comply with the Geologist and Geophysicist Act, Section 7835, 16 CCR 3003(f)(2) and CCR 3003(h), and the Professional Engineers Act, Chapter 7 of the Business and Professions Code, any report submitted to DTSC that contains geologic or engineering conclusions, recommendations, or technical interpretations must be signed or stamped by a qualified California registered geologist or professional civil engineer who takes responsibility for the technical content of the report.

PUBLIC OUTREACH

Introduction

When a vapor intrusion investigation leads to direct measurement of indoor air, a minimum of three public meetings may be necessary. The purpose of each meeting is slightly different. The first meeting is to discuss with the community the indoor sampling workplan and previous investigation results. The second meeting is to discuss the indoor air sampling results and future plans regarding the site, and additional meetings may be needed to discuss the results of additional air sampling or the remedy selection.

DTSC's Public Participation Policy and Procedures Manual (2001b) should be consulted. Following DTSC guidance, the optimal time to begin creating a trusting relationship is prior to fieldwork. The introductory meeting should explain the site investigation process and facilitate the collection of information from the community regarding their issues and concerns. As the investigation continues, the affected community should receive regular updates through fact sheets and telephone calls on the current findings and future activities. During these updates DTSC will continue to receive questions and comments from the affected community. To aid in what could be a long-term relationship, these questions and concerns must be addressed as they arise. This continuing dialogue helps to ensure that the community is aware of the facts and is prepared for future activities, such as interim actions and indoor vapor investigation. DTSC and responsible parties benefit by understanding the community and adjusting activities to minimize impact on the community when possible.

Those issues that should be the focus of public meetings specific to discussing indoor air sampling are addressed here. It is important to understand that this is only one component of an ongoing investigation and therefore is part of a larger outreach effort for the entire project.

Public Meetings

The inevitable intrusion of indoor air sampling into the personal lives of community residents and business representatives requires multiple face-to-face meetings through all phases of data collection. Although the number of meetings will vary with each project, it is important to create time to provide the following:

- Information regarding why the investigation is necessary.
- Rationale for the investigation steps and the associated questionnaires.
- Descriptions and operation of the indoor air sampling equipment.
- Explanation of the analytical results.

Each meeting should be conducted in candor and with empathy, thereby providing factual information to the community and creating trust. Information should be solicited from the community members on their preferences for these meetings. However, based upon experience, most community members require individual meetings and telephone discussions to fully address their questions. Based upon this, if the project entails working with a large number of residents and businesses, the first meeting should be held as a public forum and then breaking into small work groups to further discuss the community's questions and concerns.

The following is a suggested outline for public meetings.

1. Pre-Sampling Meeting
 - a. Introductions:
 - i. Roles and responsibilities.
 - ii. Purpose of meeting.
 - b. Site History:
 - i. Describe past hazardous waste and industrial activities.
 - ii. Describe results of groundwater and soil gas assessment (use a diagram to explain transport mechanism and extent of plume).
 - iii. Provide information on the chemicals of concern.
 - iv. Explain the results of the modeling or screening criteria.
 - c. Indoor Air Investigation:
 - i. Describe the sampling protocol.
 - ii. Discuss the sampling schedule.
 - d. Summarize meeting:
 - i. Provide copies of indoor air surveys.
 - ii. Provide a contact list with telephone numbers and email addresses.
 - iii. Provide time for questions.

2. Meeting to Discuss Sampling Results
 - a. Introductions:
 - i. Roles and responsibilities.
 - ii. Purpose of meeting.
 - b. Explain how the preferential pathways were mapped and provide the results of the investigation.
 - c. Explain results of indoor air investigation; the discussion should focus on what is known:
 - i. The results of the pre-site survey.
 - ii. The results of the site survey during sampling.
 - iii. The results of the indoor air data.
 - d. Explain the results of the risk assessment:
 - i. Provide an overview of the risk assessment process, explained in terms understandable to the general public.
 - ii. Explain the results of the risk assessment.
 - e. Explain future actions. If no future action is needed, explain to the community why no further action is required.
 - f. Summarize the meeting:
 - i. Provide copies of indoor air surveys.
 - ii. Provide a contact list with phone number and email address.
 - iii. Provide time for questions.

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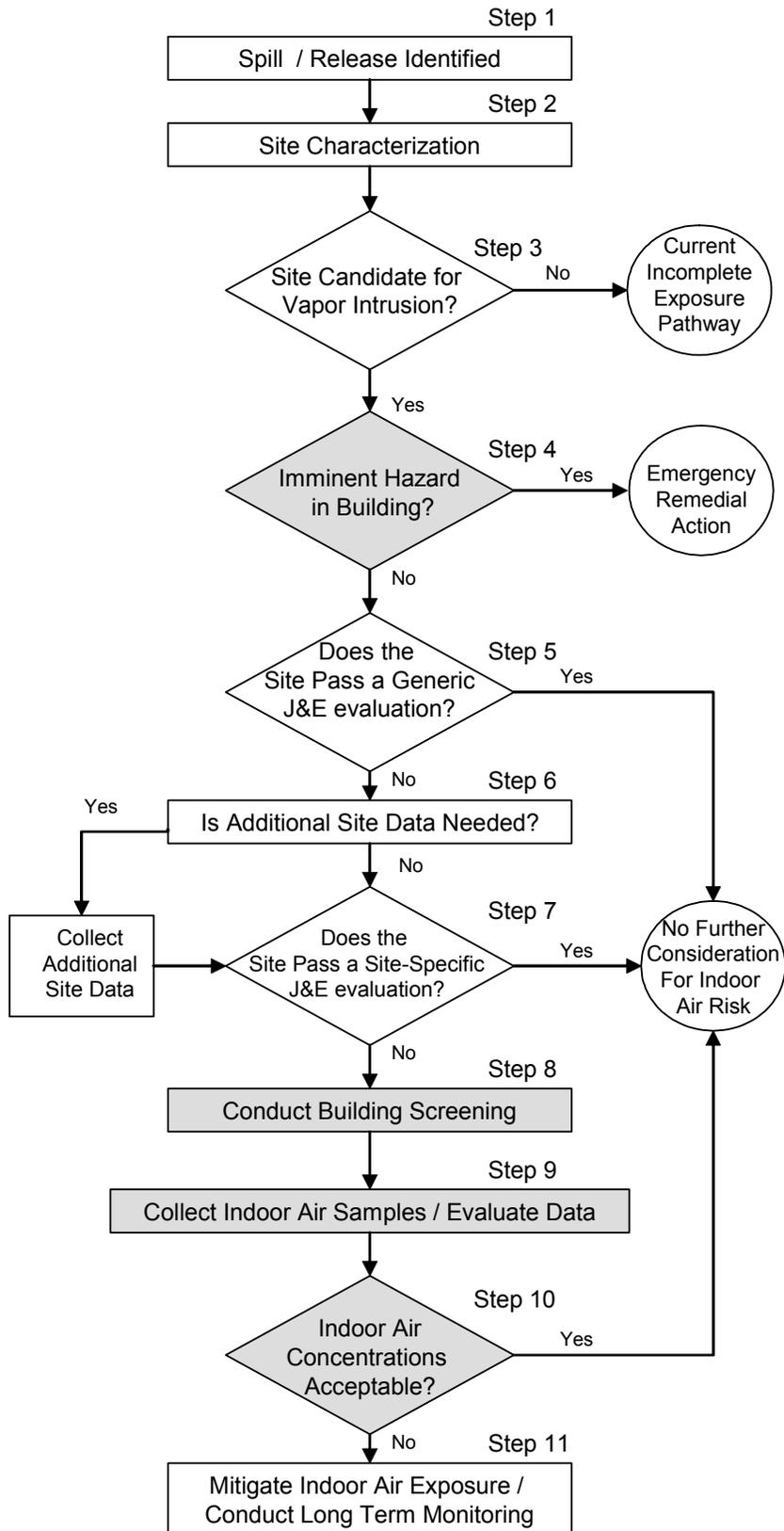
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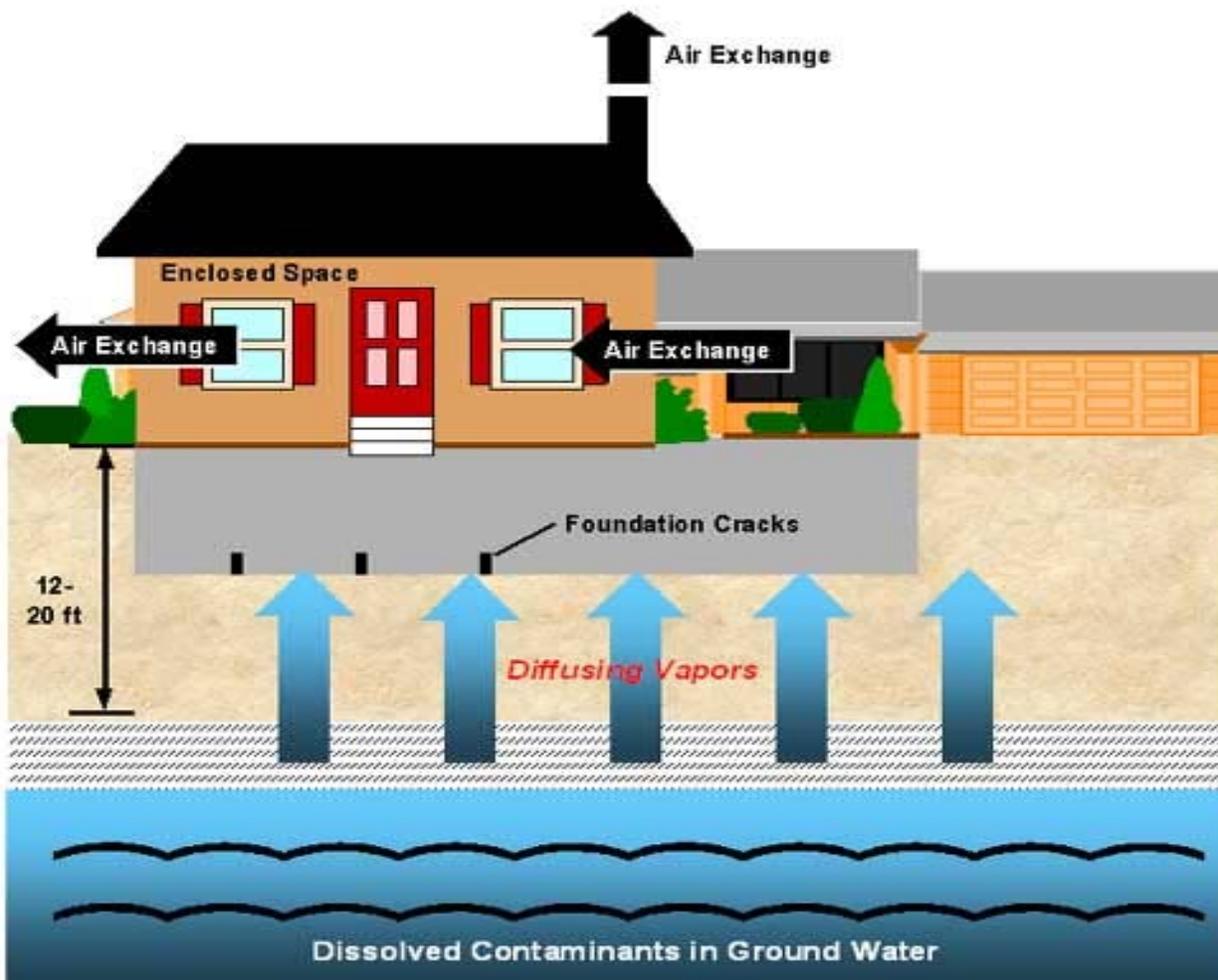
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FIGURE 1 – VAPOR INTRUSION TO INDOOR AIR ASSESSMENT



Note: Shaded steps do not apply to future building scenarios

FIGURE 2 – DIAGRAM OF AIR FLOW THROUGH A BUILDING



(Taken from ATK Alliant Techsystems, 2003).

FIGURE 3 – UTILITY CORRIDOR DECISION TREE

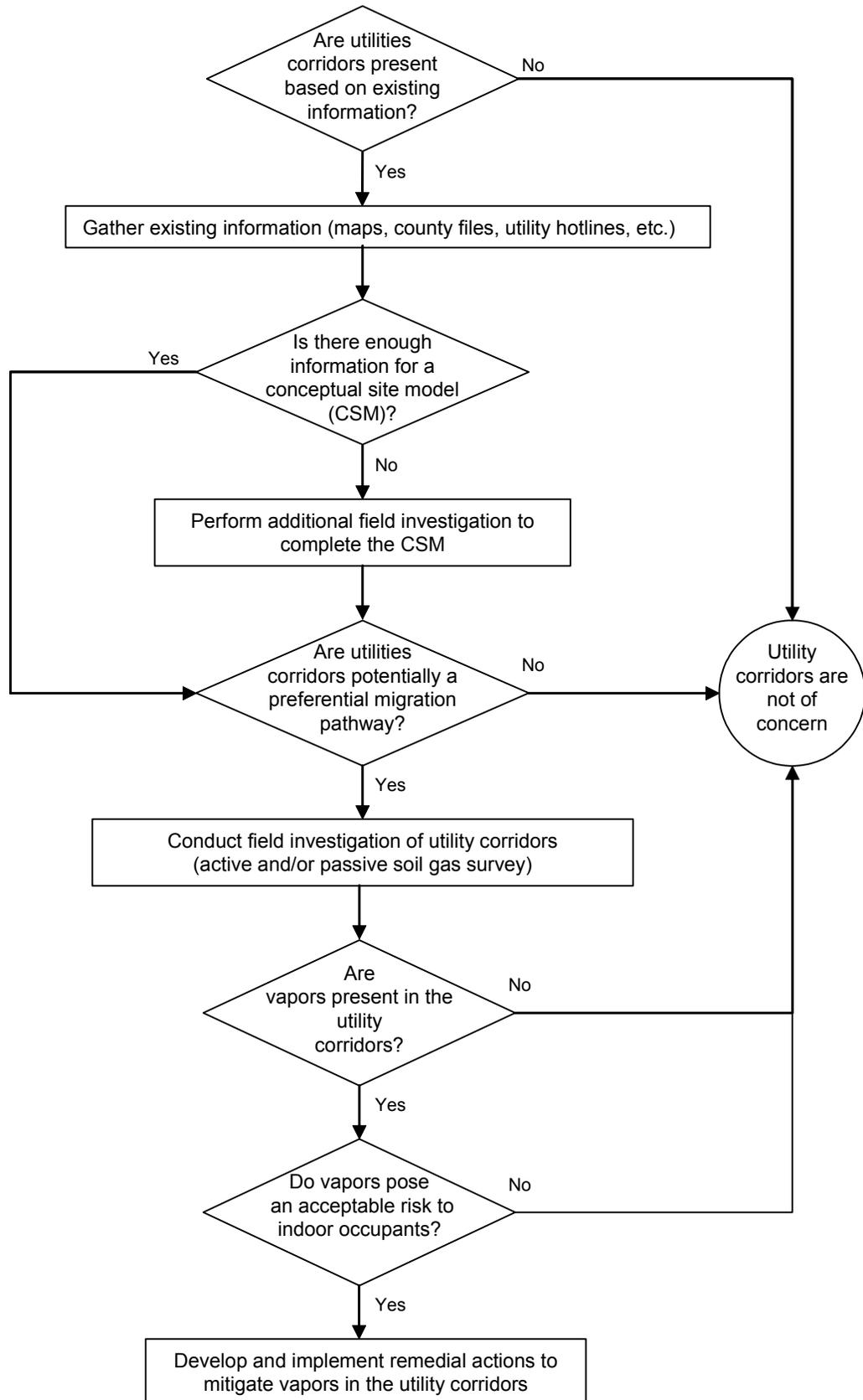


TABLE 1 - List of Chemicals to be Considered for the Vapor Intrusion Pathway

CAS Number	Chemical
630206	1,1,1,2-Tetrachloroethane
71556	1,1,1-Trichloroethane
79345	1,1,2,2-Tetrachloroethane
76131	1,1,2-Trichloro-1,2,2-trifluoroethane
79005	1,1,2-Trichloroethane
75343	1,1-Dichloroethane
75354	1,1-Dichloroethylene
96184	1,2,3-Trichloropropane
120821	1,2,4-Trichlorobenzene
95636	1,2,4-Trimethylbenzene
106934	1,2-Dibromoethane (ethylene dibromide)
95501	1,2-Dichlorobenzene
107062	1,2-Dichloroethane
78875	1,2-Dichloropropane
108678	1,3,5-Trimethylbenzene
106990	1,3-Butadiene
541731	1,3-Dichlorobenzene
542756	1,3-Dichloropropene
106467	1,4-Dichlorobenzene
123911	1,4-Dioxane
109693	1-Chlorobutane
126998	2-Chloro-1,3-butadiene (chloroprene)
95578	2-Chlorophenol
75296	2-Chloropropane
91576	2-Methylnaphthalene
79469	2-Nitropropane
83329	Acenaphthene
75070	Acetaldehyde
67641	Acetone
75058	Acetonitrile
98862	Acetophenone
107028	Acrolein (Propenal)
107131	Acrylonitrile
309002	Aldrin
319846	alpha-HCH (alpha-BHC)
100527	Benzaldehyde
71432	Benzene
205992	Benzo(b)fluoranthene
100447	Benzylchloride
92524	Biphenyl
111444	Bis(2-chloroethyl)ether
75274	Bromodichloromethane
75252	Bromoform
75150	Carbon disulfide
56235	Carbon tetrachloride
57749	Chlordane
108907	Chlorobenzene
124481	Chlorodibromomethane
75456	Chlorodifluoromethane
75003	Chloroethane (ethyl chloride)

67663	Chloroform
218019	Chrysene
156592	cis-1,2-Dichloroethylene
123739	Crotonaldehyde (2-butenal)
98828	Cumene (Isopropylbenzene)
72559	DDE
132649	Dibenzofuran
-	Dichlorobiphenyl (PCB)
75718	Dichlorodifluoromethane
60571	Dieldrin
108203	Diisopropyl Ether (DIPE)
115297	Endosulfan
60297	Ethyl ether
637923	Ethyl tert-Butyl Ether (ETBE)
141786	Ethylacetate
100414	Ethylbenzene
75218	Ethylene oxide
97632	Ethylmethacrylate
86737	Fluorene
110009	Furan
58899	gamma-HCH (Lindane)
76448	Heptachlor
87683	Hexachloro-1,3-butadiene
118741	Hexachlorobenzene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
110543	Hexane
74908	Hydrogen cyanide
78831	Isobutanol
7439976	Mercury (elemental)
126987	Methacrylonitrile
72435	Methoxychlor
79209	Methyl acetate
96333	Methyl acrylate
74839	Methyl bromide
74873	Methyl chloride (chloromethane)
1634044	Methyl tert-Butyl Ether (MTBE)
108872	Methylcyclohexane
74953	Methylene bromide
75092	Methylene chloride
78933	Methylethylketone (2-butanone)
108101	Methylisobutylketone (4-methyl-2-pentanone)
80626	Methylmethacrylate
-	Monochlorobiphenyl (PCB)
108383	m-Xylene
91203	Naphthalene
104518	n-Butylbenzene
98953	Nitrobenzene
103651	n-Propylbenzene
88722	o-Nitrotoluene
95476	o-Xylene
106423	p-Xylene
129000	Pyrene

135988	sec-Butylbenzene
100425	Styrene
994058	Tert-Amyl Methyl Ether (TAME)
75650	Tert-Butyl Alcohol (TBA)
98066	tert-Butylbenzene
127184	Tetrachloroethylene
108883	Toluene
156605	trans-1,2-Dichloroethylene
79016	Trichloroethylene
75694	Trichlorofluoromethane
108054	Vinyl acetate
75014	Vinyl chloride (chloroethene)

CAS = Chemical Abstracts Service

Table 1 was generated from the chemicals listed in the USEPA Vapor Intrusion Guidance Document (USEPA, 2002a), with the addition of fuel oxygenates and two polychlorinated biphenyl congeners due to the volatility and toxicity of monochlorobiphenyl and dichlorobiphenyl (Davis et al., 2002; Davis and Wade, 2003).

TABLE 2 - Attenuation Factors for Preliminary Screening Evaluations (Step 5)

Building Scenario	Building Type	Foundation Configuration	Attenuation Factor
Existing	Residential	Slab-on-Grade	0.002
		Crawl space	0.002
		Basement	0.01
	Commercial	Slab-on-Grade	0.001
Future	Residential	Slab-on-Grade	0.0009
		Crawl space	0.0009
		Basement	0.01
	Commercial	Slab-on-Grade	0.0004

Derivation of the attenuation factors can be found in Appendix B and OEHHA (2004).

TABLE 3 - Input Parameters for Site-Specific Screening Evaluations (Step 7)

Primary Input Parameters		Site-Specific Evaluation	Basis for Site-Specific Parameter
C_{gw}	Groundwater concentrations**	Statistical approximation*	-
C_{sg}	Soil gas concentrations**	Statistical approximation*	-
θ_t	Soil total porosity	Site-specific	Use ASTM D854
θ_w	Soil volumetric water content	Site-specific	Use ASTM D2216
θ_a	Soil volumetric air content	Site-specific	Calculate from θ_w
ρ_s	Soil bulk density	Site-specific	Use ASTM 2937
θ_{tcap}	Capillary zone total porosity	Site-specific	Use ASTM D854
θ_{wcap}	Capillary zone volumetric water content	Site-specific	Calculate from USEPA, 2003
θ_{acap}	Capillary zone volumetric air content	Site-specific	Calculate from θ_{wcap}
L_{cap}	Thickness of the capillary fringe	Site-specific	Calculate from Fetter (1994)
k	Soil permeability	Site-specific	In-situ measurement (Appendix I)
f_{oc}	Soil fraction organic carbon	Site-specific	Use Walkley-Black method
$^{\circ}T$	Soil and groundwater temperature	Site-specific	Use map in Appendix D
ΔP	Indoor – outdoor pressure differential [#]	40 g/cm-s ²	USEPA, 2002
η	Crack-to-total area ratio [#]	0.005	Johnson, 2002
E_b	Indoor air exchange rate – residential	0.5 / hour	USEPA, 1997 (California data)
E_b	Indoor air exchange rate - commercial	1.0 / hour	CEC, 2001
L_{crack}	Foundation slab thickness	Site-specific	-
L_b, W_b, H_b	Building dimensions [#]	Site-specific	-
L_f	Foundation depth below grade – building with no basement	15 cm	USEPA, 2002
	Foundation depth below grade – building with basement	200 cm	USEPA, 2002
L_t	Distance from foundation to source	Site-specific	-
L_{wt}	Distance from foundation to groundwater	Site-specific	-

USEPA = United States Environmental Protection Agency

CEC = California Energy Commission

cm = centimeters

g/cm-s² = grams per centimeter – seconds squared

Note:

* For existing buildings, the contaminant source term should be approximated with the 95th percent upper confidence limit, which can be done with ProUCL (USEPA, 2004).

** For future buildings, the maximum soil gas and groundwater concentrations should be used rather than a statistical approximation of the contaminant source.

For future buildings, a soil gas advection rate of 5 liters per minute should be used, as proportionally increased for future building size, rather than the defaults for indoor – outdoor pressure differential, crack-to-total area ratio, and foundation thickness.

APPENDIX A - FLUX CHAMBERS IN RISK DETERMINATION

Background on Flux Chambers

The development of the emission isolation flux chamber rose from the need to assess the vapor emissions from contaminated soil and other environmental media at Superfund sites as part of remedial investigation efforts. To measure emissions from soil, an enclosure or chamber is used to isolate a soil surface. The flux chamber approach gives a direct measurement of the subsurface contaminant flux at the soil-air interface as driven by diffusion and atmospheric conditions. The flux chamber results are then used to evaluate the impact of contaminated soil and other media on ambient air quality. The assessment of emissions of volatile organic compounds (VOCs) with flux chambers are usually done in conjunction with either TO-14A (United States Environmental Protection Agency [USEPA], 1999) or TO-15 (USEPA, 1999), as appropriate, yielding analytical detection limits of 0.1 to 0.001 micrograms per liter ($\mu\text{g/L}$) for the air within a flux chamber.

There are two types of flux chamber methods; the static chamber method and the dynamic chamber method. For the dynamic method, a sweep gas is continuously introduced into the chamber during the incubation period and an equivalent amount of chamber gas is allowed to escape. The chamber is assumed to reach a steady-state condition after the chamber has been swept by the sweep gas four or five times. At steady-state conditions, the contaminant concentration in the outlet gas is equivalent to the concentration in the chamber. The outlet gas can either be sampled periodically over the incubation time at four to six hours intervals, or sampled continuously through capture within a Summa™ canister, thus yielding an integrated sample.

In the static chamber method, there is no introduction of a sweep gas into the chamber during the incubation period. Contaminants migrate into the static chamber and the contaminant concentration builds-up over time. Discrete samples for analysis are withdrawn either at the end of the incubation period or at regular intervals during the incubation period. The required equipment for static testing is very simple, consisting essentially of a collection container with sampling ports.

USEPA Publications on the Use of Flux Chambers

Radian Corporation, under contract to USEPA, developed procedures for the use of emission isolation flux chambers for evaluating the flux of chemicals from the soil-air interface (USEPA, 1986). While the Radian document describes the construction of flux chambers and procedures for the collection of flux chamber data in the field, the USEPA document is a technical reference only. The document provides no information concerning the use of flux chambers to quantify human health risk associated with vapor emissions from the subsurface. Subsequent USEPA technical documents (USEPA 1990, 1992b, and 1992c) discuss the general application of flux chambers for evaluating the impact of contaminated soil and other media on ambient air quality. These subsequent documents do not address the use of flux chambers for the evaluation of vapor intrusion. To date, USEPA has not developed procedures for the use of flux chambers for the evaluation of the vapor intrusion pathway and the use of flux chambers as a mechanism to quantify the health risk for indoor human receptors.

It should be noted, however, that USEPA (1992a) recommended that flux chambers should not be used to evaluate the vapor intrusion to indoor air pathway. The 1992 USEPA

document states that “flux chambers. . . may give significantly negatively biased results if building underpressurization is exerting an effect on soil gas flow rates” and that “low permeability zones near the surface, frozen ground, or wet surfaces may also result in low flux chamber results.” The 1992 USEPA guidance document recommends that soil gas samples be collected as a mechanism to evaluate vapor intrusion to indoor air.

In 2002, USEPA generated regulatory guidance for the evaluation of vapor intrusion (USEPA, 2002b). The document was generated as official USEPA guidance and was noticed in the Federal Register on November 29, 2002. The guidance document recommends quantifying subsurface contaminant sources through soil gas sampling and groundwater sampling and then using this data as a means to evaluate the indoor air exposure pathway. The 2002 USEPA guidance document provides screening values for both soil gas and groundwater that are protective of human exposure to vapor intrusion from subsurface contamination. No where in the guidance document is information provided on using flux chambers to quantify the impact of subsurface contamination on indoor air receptors. However, USEPA implies that flux chamber measurements can be used as an additional line of evidence to soil gas for evaluating vapor flux from the subsurface at brownfield sites where no buildings exist. Accordingly, in their guidance document, USEPA did not recommend flux chambers as a primary mechanism to evaluate the vapor intrusion to indoor air pathway.

Indoor Flux Chamber Measurements for the Evaluation of Indoor Air

The soil gas entry points into a building are along cracks or voids at the structural footings, along the cracks or voids at the foundation-wall interface, along the utility conduit entry points into the structure, and at the cracks or voids within the foundation and basement walls. The design of the flux chamber precludes the use of the chamber in all these scenarios except for foundation cracks or voids where the chambers can be placed directly on flat-lying cracks or voids. Therefore, testing only the foundation cracks or voids within a building will not yield representative samples for indoor air quality evaluation due to the existence of other potential soil gas entry points.

Furthermore, even if foundation cracks or voids are the sole entry point for soil gas into a building, difficulties still exist in using flux chambers to evaluate indoor air quality. When evaluating a foundation slab, selection of the flux chamber measurement locations is crucial to the success of the evaluation. Without access to the entire foundation, it becomes impossible to select appropriate areas for testing. Hence, for residential structures where the foundation slab is entirely covered with carpet, tile, or linoleum, representative flux chamber sampling is not possible due to an unwillingness to remove all floor covering in a residential building. Additionally, even if an entire foundation slab is available for flux chamber testing in a residential or commercial building, it is difficult to know which subset of cracks or voids are responsible for the degradation of indoor air quality.

DTSC recommends that indoor air quality evaluations be conducted with a method other than flux chambers for the evaluation for the vapor intrusion pathway. Flux chamber measurements cannot evaluate all possible soil gas entry points into a building due to design limitations of the chamber and it is doubtful that flux chambers can measure the total flux into a building due to the inability to place the chambers on the slab cracks or voids that are representative of vapor flux into the building.

Soil Flux Chamber Measurements for the Evaluation of Indoor Air

Flux chamber measurements of open soil surfaces may not be representative of actual contaminant fluxes into buildings. The measured flux could be biased high due to the lack of a building foundation impeding the movement of vapors. Conversely, the measured flux could be biased low because the flux chamber cannot duplicate the pressure-induced advective flow caused by a building's depressurization.

When using flux chamber measurements on open soil, one method to account for vapor attenuation over the foundation slab is to divide the flux measurements by a foundation crack-to-total area ratio (Copeland et al., 2002), which is usually taken as 0.01 (American Society for Testing and Materials [ASTM], 1995; ASTM, 2000). While this approach has been used in the past as a method to determine indoor air concentrations from outdoor flux chamber measurements, the approach has not been field validated. There are no peer reviewed scientific articles that specifically provide documentation that this procedure is appropriate for evaluating risk to indoor receptors.

The intrinsic design of the flux chamber only allows for the measurement of vapors moving into the chamber by diffusion or by atmospheric driven advection due to ambient temperature and pressure changes. Hence, the flux chamber cannot measure vapor movement driven by a building's heating and ventilation system. To address the issue of building induced advection flow, Sheldon and Schmidt (2002) developed and tested a procedure that allows the flux chamber to depressurize to values observed in buildings. The intent of the depressurization procedure is to create a "mini-building" in which flux measurements could be made. However, the induced depressurization of the flux chamber to mimic building depressurization will need field validation prior to regulatory acceptance. This limitation, and the limitation associated with quantification of the foundation attenuation, seriously inhibits the flux chamber as a means to directly evaluate vapor intrusion to indoor air. Hence, flux chamber measurements of open soil surfaces should only be used qualitatively for vapor intrusion evaluations.

Soil Flux Chamber Measurements for the Evaluation of Outdoor Air

The testing of surface soil with flux chambers yields the amount of VOCs being released through diffusion and atmospheric conditions at the soil-air interface. From the soil flux data, the VOC concentrations in ambient air can be estimated. Using an appropriate box model, along with the flux chamber measurements, the ambient concentrations of VOCs within the breathing zone in outdoor air can be determined. Therefore, flux chamber measurements can be used to satisfactorily quantify human exposure to outdoor air contaminated from VOCs from subsurface sources. This exposure pathway, subsurface soil to outdoor air, is the sole exposure pathway where flux chambers measurement can be used to quantify exposure inhalation from vapors migrating from the subsurface.

Additional Concerns About the Use of Flux Chambers

Heating of Flux Chambers During Sampling

Surface warming on metal flux chambers due to direct sunlight and ambient conditions, and associated greenhouse effects on transparent chambers, may cause the internal air temperature inside a flux chamber to increase during sample collection. As temperatures increase inside the flux chamber, the air pressure inside the flux chamber may also

increase. If internal heating is significant, an associated back-pressure may inhibit the diffusional movement of air from the subsurface into the chamber if the sweep gas cannot compensate for the pressure buildup. Therefore, the flux chamber should be shaded from direct sunlight during sampling and should not be used on days with extreme temperature variations. In typical applications of the flux chamber, measurements of the internal air pressure are not taken so there is no indication if air is exiting into the soil, inhibiting vapor flux. Ideally, these measurements should be taken to verify the air mass balance during the operation of the flux chamber. Additionally, no peer reviewed scientific literature is available that evaluates the heating of flux chambers during sample collection.

Rainfall Events

A rainfall event of 0.3 inches of water has been observed to decrease emission rates into flux chambers by ninety percent, and a minimum of seven days of hot, sunny weather were required before gas emission rates from soil returned to values equal to that before the rainfall event (USEPA, 1986). Hence, outdoor flux chamber measurements should only be taken after warm dry weather. Additionally, due to moisture blockage of potential soil gas emissions, flux chamber measurements should not be taken in areas subject to irrigation or in areas of commercial or residential landscaping.

Atmospheric Pressure Effects

The work by Massmann and Farrier (1992) indicates that “fresh” atmospheric air may migrate several meters into the subsurface during a barometric pressure cycle. Massmann and Farrier concluded that the intrusion of atmospheric air into the subsurface may affect the results of soil gas surveys because the concentration of VOCs within the subsurface may be lowered when barometric pressures are high. Likewise, flux chamber measurements would also be effected by barometric pressure changes. The occurrence of these phenomena has not been addressed within the scientific literature. However, the effects of barometric pumping on sampling results for indoor air have been recognized by other state agencies (Massachusetts Department of Environmental Protection, 2002). Thus, the proper deployment of flux chambers to obtain representative samples as a function of barometric pressure variations is not well understood.

Condensation of Water During Sampling

During sample collection, condensation may occur inside the flux chamber due to changing ambient pressure and temperature conditions. Condensation may reduce VOC concentrations in the flux chamber air due to partitioning of water soluble VOCs into the condensation during chamber deployment. Hence, the occurrence of condensation should be noted in the field and reported to DTSC with the understanding that the sampling results may be biased low due to chemical partitioning.

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APPENDIX B – DEFAULT ATTENUATION FACTORS

Future Residential Slab-On-Grade Buildings

Pursuant to Senate Bill 32 (SB 32), the California Land Environmental Restoration and Reuse Act, the Office of Environmental Health Hazard Assessment (OEHHA) published a list of risk-based screening numbers (OEHHA 2004). Numerous exposure pathways were evaluated in calculating the SB 32 screening numbers, including vapor intrusion to indoor air. To evaluate vapor intrusion for future slab-on-grade buildings, OEHHA used the Johnson and Ettinger (J/E) (1991) model as programmed into Microsoft EXCEL™ by the United States Environmental Protection Agency (USEPA Vapor Intrusion Model) (USEPA, 2003). The model input parameters and the rationale for their selection can be found in the OEHHA document. Additionally, OEHHA used toxicity factors specific to California. The average attenuation factor for future residential slab-on-grade buildings from the OEHHA document is 0.0009.

Existing Residential Slab-On-Grade Buildings

OEHHA published a list of risk-based screening numbers for vapor intrusion into existing residential slab-on-grade buildings, and again, used the USEPA Vapor Intrusion Model for the evaluation. The model input parameters and the rationale for their selection can be found in the OEHHA document. Additionally, OEHHA used toxicity factors specific to California. The average attenuation factor for existing residential slab-on-grade buildings from the OEHHA document is 0.002.

Buildings With Crawl Spaces

No vapor attenuation should be assumed over a building's crawl space. Hence, future and existing buildings with crawl spaces should be evaluated as though constructed with a slab-on-grade foundation. This implies that the attenuation over the crawl space is 1.0 and this approach is consistent with USEPA guidance (2002a). Likewise, the empirical data shown at the 2004 Conference of the Association of Environmental Health and Science indicates that crawl space attenuation is minimal (Dawson, 2004). Thus, the attenuation factors for residential buildings with crawl spaces, whether they are future or existing structures, are equal to the attenuation factors for slab-on-grade structures.

Buildings With Basements

The attenuation factor for residential buildings with basements is taken from the USEPA empirical database on vapor intrusion. Because basements are often poorly ventilated, DTSC assumed that subslab attenuation factors are appropriate for evaluating residential buildings with basements. USEPA (2002a) recommends an attenuation factor of 0.1 for subslab attenuation. More recently, however, empirical data shown at the 2004 Conference of the Association of Environmental Health and Science suggested that subslab attenuation factors may be closer to 0.01 (Dawson, 2004). Accordingly, an attenuation factor of 0.01 should be used when evaluating subslab attenuation and hence basement attenuation. This is appropriate in that many of the sites in the USEPA database related to subslab attenuation are from buildings with basements.

Existing and Future Commercial Buildings

The attenuation factors for existing and future commercial buildings were derived by OEHHA in a similar fashion as the residential attenuation factors. The residential attenuation factors for slab-on-grade buildings were decreased to account for the higher indoor air exchange rates for commercial buildings. Default air exchange rates for residential buildings is 0.5 air exchanges per day while commercial air exchanges rates are 1.0 air exchange per day. Likewise, OEHHA decreased the exposure frequency and exposure duration of the buildings occupants to reflect the commercial worker scenario. Hence, the attenuation factors for future and existing commercial buildings are 0.0004 and 0.001, respectively.

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APPENDIX C – HUMAN RISK ASSESSMENT

When a site or facility first comes to the attention of the DTSC, the question to be answered is, has there been a release of hazardous chemicals that could pose a risk to human health or the environment and require further evaluation by and oversight of the DTSC? During this initial stage, as described in the DTSC Preliminary Endangerment Assessment Guidance Manual, a *health screening evaluation* may be performed, applying conservative default assumptions to a limited data set, to answer that question. If this screening evaluation shows that the risks are insignificant, then the DTSC can recommend no further action, and the site is released from DTSC oversight requirements. An insignificant risk resulting from long-term exposure to chemicals present is one in which the theoretical excess risk of getting cancer is less than one-in-a-million (10^{-6}) or the hazard index is less than one for non-cancer effects. However, if the screening evaluation shows that the theoretical excess cancer risk is greater than 10^{-6} or the hazard index is greater than one, further investigative studies are conducted in order to fully characterize the site, determine the extent of contamination, and reevaluate the risk and hazard posed by the contaminants present by performing a *health risk assessment*.

If volatile organic chemicals are present, the health risk assessment would include the evaluation of the following exposure pathways:

- Inhalation of vapors that have intruded to indoor air from the subsurface (soil, soil gas, shallow groundwater).
- Inhalation of vapors outdoors coming from the subsurface (soil, soil gas, shallow groundwater).
- Inhalation of vapors coming from groundwater contaminated with volatile organic chemicals being used as tap water (in showering and general household use),
- Ingestion of groundwater contaminated with volatile organic chemicals used as tap water.

Recent experience of environmental regulatory agencies indicates that vapor intrusion is the most significant pathway for volatile organic chemicals, that is, it is the exposure pathway that usually drives the risk from long-term (chronic) exposure to this class of chemicals. Therefore, it is the pathway that has the greatest effect on the calculations performed to estimate concentration(s) of volatile chemicals that may be safely left behind after remediation or corrective action. The following exposure pathways are not usually relevant for volatile chemicals:

- Incidental ingestion of soil contaminated with volatile organic chemicals.
- Dermal contact with soil contaminated with volatile organic chemicals.
- Ingestion of food products contaminated with volatile organic chemicals in soil and groundwater.

The remainder of the discussion below focuses on the evaluation of the indoor air exposure pathway only. The approach for evaluation of all other exposure pathways associated with volatile organic chemicals is described in other USEPA and DTSC guidance documents (USEPA Risk Assessment Guidance for Superfund, Volume 1 Human Health Evaluation Manual (Part A), 1989; DTSC Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities, 1993; USEPA Soil Screening Guidance, 1996).

Overview of the Human Health Risk Assessment Process

The human health risk assessment process for a facility or site has four parts: 1) data collection and evaluation, 2) exposure assessment, 3) toxicity assessment, and 4) risk characterization. In *data collection and evaluation*, site conditions are characterized, potential chemicals of concern are identified, and the nature and extent of contamination are determined in a site investigation.

The *exposure assessment* builds on the results of the site investigation. The concentrations of the chemicals of concern in environmental media (soil, air, water) are evaluated in the framework of a chosen land use scenario (residential, industrial, recreational, etc.). Exposure pathways that would be associated with that land use are identified, and the exposure (or potential dose) to the chemicals of concern are quantified. Included in exposure assessment is the modeling of chemicals from the point of release to the point of exposure (fate and transport modeling). With respect to the indoor air exposure pathway, fate and transport modeling may be used to simulate the diffusion of a chemical released to soil or present in groundwater (the source) upward as a vapor through soil pores towards the surface and the pressure-driven flow of the vapor from soil through a building foundation and into indoor air (the point of exposure). The efforts of the DTSC in site investigations are primarily in data collection, data evaluation and exposure assessment.

Toxicity assessment refers to the identification of a chemical as one that may cause an adverse health effect under certain conditions of exposure and the dose of that chemical necessary to cause that effect. Numeric toxicity criteria have been developed by regulatory agencies for chemicals commonly found at chemical release sites that define the toxicity of the chemical. Two kinds of toxicity criteria are used in human health risk assessments. A reference dose (RfD) or reference concentration in air (RfC) for a chemical is a daily exposure level for a human that will not result in an adverse non-cancer health effect. A cancer slope factor (CSF) or unit risk factor (URF) for a chemical is an expression of the potency of that chemical to cause cancer. The CSF or URF represents the probability (risk) of the chemical to cause cancer after a lifetime of exposure.

In *risk characterization*, the calculated exposure dose and toxicity criteria are brought together to develop an estimate of hazard (referring to non-cancer effects) and of risk (referring to the probability of getting cancer as a result of a lifetime of exposure to the chemical). These equations are given in the Risk Equations section below.

Land Use Assumptions

The residential home dweller is the default exposure scenario, because the parameters used to define this scenario are usually the most conservative. For example, it is assumed in this scenario that the resident remains at home 24 hours per day and lives in the same home for 30 years. The indoor worker is the most common alternative site-specific exposure scenario. It is assumed in this scenario that the work day is eight hours, and the worker remains at the same job or facility for 25 years.

Risk Equations in Indoor Air Inhalation Exposure

The equation used to calculate the theoretical excess cancer risk from inhalation exposure to volatile chemicals may be expressed as:

$$\text{Risk} = \frac{C_{\text{building}} \times \text{EFD} \times \text{URF}}{\text{AT}_c \times 365 \text{days/year}}$$

The equation used to calculate the hazard quotient (HQ) for inhalation exposure to noncarcinogenic volatile chemicals may be expressed as:

$$\text{Hazard Quotient} = \frac{C_{\text{building}} \times \text{EFD} \times 1/\text{RfC}}{\text{AT}_{\text{nc}} \times 365 \text{days/year}}$$

Where:

C_{building}	=	Chemical concentration in the exposure medium of indoor air in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$); this value is either determined by fate and transport modeling or is equal to the value measured by indoor air sampling.
EFD	=	Exposure frequency and duration, describing how long and how often exposure occurs, usually calculated using two terms:
EF	=	Exposure frequency in days per year.
ED	=	Exposure duration in years.
AT	=	Period of time over which exposure is averaged in days.
AT_c	=	Averaging time for carcinogens, 70 years.
AT_{nc}	=	Averaging time for noncarcinogens, equal to the exposure duration.
URF	=	Unit risk factor, representing the increase in risk per micrograms of chemical inhaled per cubic meter ($\mu\text{g}/\text{m}^3$) ⁻¹ .
RfC	=	Reference concentration, the concentration to which humans may be exposed without risk of adverse health effects during a lifetime, in $\mu\text{g}/\text{m}^3$.

These equations may be rearranged to calculate the building concentration that would be considered safe by setting a target risk (usually one-in-a-million (10^{-6}) or one-in-a-hundred-thousand (10^{-5})) and target hazard quotient (always 1.0). A fate and transport model may then be used to calculate the relevant environmental medium concentration that would result in the target building concentration.

Using the USEPA Vapor Intrusion Model

In the USEPA Vapor Intrusion Model spreadsheets, as modified by the DTSC, environmental media concentrations (groundwater, soil gas) are input into the spreadsheet along with default or site-specific input parameters describing the characteristics of the subsurface (total soil porosity, fraction of organic carbon, soil bulk density, soil water-filled porosity, air permeability, depth to contamination, etc.). The overall objective of the model is to calculate the attenuation factor “alpha” (α), which is the ratio of indoor air concentration to soil gas concentration. The model does this by using soil gas data and simulating the migration of the vapor upwards and into indoor air. If groundwater data are used in the USEPA Vapor Intrusion Model, the model converts the groundwater concentrations to soil vapor concentrations before performing the simulation. The calculated indoor air concentration represents the exposure medium concentration, C_{building} , in the equations

above. Finally, the USEPA Vapor Intrusion Model performs the risk calculations to provide the risk and hazard posed by the chemical. A discussion of the fate and transport part of this model is found in Appendix D.

Exposure Parameters

The exposure parameters recommended by the DTSC for the evaluation of the indoor air pathway are the same as those recommended by the USEPA in various guidance documents (USEPA Risk Assessment Guidance for Superfund (RAGS) (1989); USEPA Soil Screening Guidance (1996); USEPA Exposure Factors Handbook (1997)) and those used by the California Environmental Protection Agency (Cal/EPA) Office of Environmental Health Hazard Assessment (OEHHA) in their development of human exposure-based soil screening numbers (2004). The relevant generic exposure parameters for this pathway assume residential land use and are:

EF	=	Exposure frequency, 350 days per year.
ED	=	Exposure duration, 30 years.
AT _c	=	Averaging time for carcinogens, 70 years.
AT _{nc}	=	Averaging time for non-carcinogens, 30 years.

Two other exposure parameter values, body weight (70 kg) and contact or intake rate (breathing rate: 20 cubic meters per day) are incorporated into the URF and RfC. These are the default exposure parameters used in the USEPA Vapor Intrusion Model.

Site-Specific Exposure Parameters

Of all the human exposure parameters, changing the exposure duration (ED) has the greatest effect on calculating the intake of the chemical. In site-specific circumstances, it is possible to decrease the exposure duration with appropriate documentation. For example, in an occupational setting where it is expected that current operations will continue to the foreseeable future, employment records for the facility may be used to estimate a reasonable duration of employment.

Toxicity Criteria

A unit risk factor (URF, $(\mu\text{g}/\text{m}^3)^{-1}$) is the toxicity criterion defining the potency of carcinogenic chemical when inhaled. A chronic reference concentration (RfC, $\mu\text{g}/\text{m}^3$) for a chemical is derived from the threshold concentration where no adverse health effects are expected to occur from long-term exposure to that chemical. Numeric toxicity criteria have been developed for specific chemicals by OEHHA and USEPA. The DTSC uses those criteria developed by OEHHA in human health risk assessments. If a criteria value does not exist for a specific chemical, the DTSC uses USEPA values. The DTSC Human and Ecological Risk Division (HERD) version of the USEPA Vapor Intrusion Model contains the toxicity criteria acceptable to the DTSC. These criteria are automatically called-up from the model's look-up table when the chemical to be evaluated is identified.

Occupational Standards Versus Risk-Based Standards

Although USEPA and the Occupational Safety and Health Administration (OSHA) have agreed that OSHA Permissible Exposure Limits (PELs) will be used as concentration thresholds in occupational exposures at chemical release facilities, DTSC HERD and

USEPA regional risk assessors object to this use of OSHA PELs as protective concentration thresholds in the workplace. DTSC notes that OSHA PELs are not intended to protect against “continuous, uninterrupted exposures or other extended work periods” (Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists, 1994-1995). Furthermore, OSHA PELs are not indices of toxicity and, thus, cannot be assumed to protect all workers. Rather, OSHA PELs assume that the potentially exposed worker has been trained in workplace regulations and is subjected to routine biomedical monitoring, as necessary. This means that office workers at a chemical release facility who have not been so trained, who do not have access to protective gear, and/or are not protected by other environmental controls, may be at risk if only OSHA PELs are invoked as concentration thresholds in their workplace. Therefore, DTSC recommends that the health risk assessment approach as discussed in this guidance be utilized for all land use exposure scenarios, including the indoor worker scenario (see Appendix F for more information).

Cumulative Risk Calculations

The USEPA Vapor Intrusion Model calculates the risk or hazard posed by a single, specific chemical intruding into indoor air spaces from the subsurface, resulting in exposure by inhaling contaminated indoor air – a single exposure pathway. It is important to remember that a human health risk assessment for a site or facility must include the risks and hazards posed by all chemicals of concern detected and all complete exposure pathways. This is done by first summing the risks and hazards posed by all chemicals via each, separate, complete exposure pathway, then by summing the risks/hazards from all complete exposure pathways.

The cumulative risk or hazard for the indoor air exposure pathway is calculated by summing the individual risk/hazard of each evaluated volatile chemical. This may be done one of several ways. In all of the three alternative methods described below, the first thing that must be done is to identify each volatile chemical detected at the site as a carcinogen or a non-carcinogen. All carcinogens are summed separately from the non-carcinogens.

Comparing the site soil vapor concentration of a chemical to OEHHA human-exposure-based soil vapor screening number for that chemical

Screening numbers have been published by OEHHA for many of the toxic volatile chemicals found at chemical release sites. As described in this guidance, these numbers may be used in the initial human health evaluation of a site. For sites where more than one volatile chemical has been detected, cumulative risks and a hazard index for all the chemicals found are calculated as follows.

For sites with more than one non-carcinogenic volatile chemical contaminant, the hazard index is calculated by summing the ratio of the hazard quotient of each chemical. For non-carcinogenic chemical species S_1, S_2, \dots, S_n with soil vapor concentrations C_1, C_2, \dots, C_n and OEHHA soil gas screening numbers SN_1, SN_2, \dots, SN_n , the non-carcinogenic hazard index is:

$$\text{Hazard Index} = C_1/SN_1 + C_2/SN_2 + \dots + C_n/SN_n$$

It is vital that the soil vapor screening number used in this Hazard Index calculation has been identified as being based on a reference level for chronic toxic effects other than

cancer.

For sites with more than one carcinogenic chemical contaminant, the cumulative cancer risk is calculated by summing the ratios and multiplying the sum by 10^{-6} . For carcinogenic chemical species S_1, S_2, \dots, S_n with soil vapor concentrations C_1, C_2, \dots, C_n and soil gas screening numbers SN_1, SN_2, \dots, SN_n , the cancer risk is calculated using the expression:

$$Risk = [C_1/SN_1 + C_2/SN_2 + \dots + C_n/SN_n] \times 10^{-6}$$

The soil vapor screening number used in this risk calculation must be based on a carcinogenic potency factor.

Comparing the indoor air concentration calculated using the attenuation factors given in Step Five, Preliminary Screening Evaluation, to OEHHA Target Indoor Air Concentrations

In the OEHHA document, *Human-Exposure-Based Screening Numbers Developed to Aid Estimation of Cleanup Costs for Contaminated Soil* (December 2004), a list of target residential indoor air concentrations for specific chemicals is given in an appendix.

Once the indoor air concentration for a chemical has been calculated using the method described in Step Five of this guidance document, the hazard index and cumulative risk posed by all volatile organic chemicals found at the site from the indoor air inhalation exposure pathway is calculated in a similar fashion as described above.

The hazard index is calculated by summing the ratio of the hazard quotient of each chemical. For non-carcinogenic chemical species S_1, S_2, \dots, S_n with calculated indoor air concentrations $IAC_1, IAC_2, \dots, IAC_n$ and OEHHA target indoor air concentrations $TIAC_1, TIAC_2, \dots, TIAC_n$, the non-carcinogenic hazard index is:

$$Hazard\ Index = IAC_1/TIAC_1 + IAC_2/TIAC_2 + \dots + IAC_n/TIAC_n$$

The TIACs used in this Hazard Index calculation must be based on a reference level for chronic toxic effects other than cancer.

The cumulative cancer risk is calculated by summing the following ratios and multiplying the sum by 10^{-6} . For carcinogenic chemical species S_1, S_2, \dots, S_n with calculated indoor air concentrations $IAC_1, IAC_2, \dots, IAC_n$ and OEHHA target indoor air concentrations based on carcinogenic potency factors $TIAC_1, TIAC_2, \dots, TIAC_n$, the cancer risk is calculated using the expression

$$Risk = [IAC_1/TIAC_1 + IAC_2/TIAC_2 + \dots + IAC_n/TIAC_n] \times 10^{-6}$$

As stated in the previous section, the target indoor air concentration used in this risk calculation must be based on a carcinogenic potency factor.

Adding the risks and hazard quotients calculated using the USEPA Vapor Intrusion Model as modified by the DTSC

In those circumstances where the USEPA Vapor Intrusion Model spreadsheet is used to calculate the chemical-specific risk or hazard quotient posed by a chemical intruding into indoor air, the method used to calculate the cumulative risk or hazard posed by all the

volatile chemicals detected at the site is very simple. The incremental risk calculated for each chemical is simply added together to get the cumulative cancer risk, and the hazard quotient calculated for each chemical is added together to get the hazard index for this exposure pathway.

Uncertainties

In the fate and transport modeling of chemicals through the environment and the health risk assessment of those chemicals, assumptions must be made since there is never complete information about the physical aspects of a site, and there is no way to accurately predict future exposures and consequent risks from those exposures. Therefore, these assumptions must be reasonably conservative in order to be protective of human health but not so conservative as to be outside of the range of probability. DTSC recommends that all health risk assessments contain an uncertainty section that attempts to define and discuss the major assumptions and uncertainties inherent in the assessment. With respect to the indoor air exposure pathway, some of the uncertainties that should be discussed are discussed below.

Uncertainties that could result in a risk or hazard greater than that calculated:

- The existence of unidentified preferential pathways in the subsurface that would facilitate the movement of soil vapors into indoor air spaces, such as, naturally occurring geologic faults, the presence of permeable fill material below foundations, openings in the foundation slab made for electrical conduits, plumbing, drainage, space heating, and cooling equipment.
- A decrease in ventilation rates in current and future buildings on site that could lead to a buildup of toxic contaminants in indoor air intruding from the subsurface.
- The biotransformation of a chemical from a relatively benign compound to a more toxic compound, such as the transformation of numerous precursors to vinyl chloride.

Uncertainties that could result in a risk or hazard lower than that calculated:

- A reduction in exposure duration of residents and workers over the contaminated subsurface.
- A decrease over time in the contaminant mass in the subsurface available for volatilization into soil pore spaces.
- The biodegradation of a volatile chemical in soil over time leading to decreasing exposure over time.

APPENDIX D – OVERVIEW OF THE JOHNSON AND ETTINGER MODEL

Fate and transport models can assist in evaluating the degradation of indoor air quality due to the intrusion of subsurface volatile contaminants. However, models are not intended to serve as the exclusive approach for evaluating human health risk due to vapor intrusion. When used in combination with site-specific information, the results of modeling will add to the overall weight of evidence used to evaluate the exposure pathway. The Johnson and Ettinger (1991) model (J/E) is one of the most commonly used models for evaluating the indoor air exposure pathway. DTSC has selected the J/E model as the recommended approach to evaluate the vapor intrusion pathway in California. USEPA programmed the J/E model into Microsoft EXCEL™ and added a health risk component that calculates the risk from inhaling the specific chemical at the concentration estimated in indoor air. Examples of the USEPA Vapor Intrusion Model as modified by DTSC can be found on DTSC's webpage. However, other vapor intrusion models are available and the intent of this Guidance is not to exclude the use of different models to evaluate indoor air quality. The use of any model at a site besides the USEPA Vapor Intrusion Model should be approved by DTSC during the workplan stage prior to use of the model to evaluate risk.

The J/E model is a simple, deterministic model, having single-point inputs and outputs. The J/E model is based on the basic principles of contaminant fate and transport, contaminant partitioning between media, and the physical and chemical properties of the contaminants themselves. The model incorporates both diffusion and advection as mechanisms of transport of subsurface vapor into the indoor air environment. Diffusion is the mechanism by which vapor moves from high concentration to low concentration due to a concentration gradient. Advection is the transport mechanism by which vapor moves due to differences in pressure. For the J/E model, diffusion is the dominant mechanism for vapor transport within the vadose zone. Once the vapor enters into the "building zone of influence", the vapors are swept into the building through foundation cracks by advection due to the indoor – outdoor building pressure differential. The distance of the "building zone of influence" is usually less than a few feet. The J/E model uses the conservation of mass principle and is based on the following assumptions:

- Steady-state conditions exist.
- An infinite source of contamination exists.
- The subsurface is homogeneous.
- Air mixing in the building is uniform.
- Preferential pathways do not exist.
- Biodegradation of vapors does not occur.
- Contaminants are homogeneously distributed.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.
- Buildings are constructed on slabs or with basements.
- Ventilation rates and pressure differences are assumed to remain constant.

The J/E model is widely used across the United States to model vapor intrusion. However, the J/E model cannot evaluate preferential migration pathways and fractured bedrock conditions. Each of these conditions has the potential to significantly increase the rate of vapor intrusion beyond what the model would predict. With an understanding of the above-mentioned limitations, the J/E model can allow users to quickly screen sites for vapor intrusion risk. The output of the J/E model is the dimensionless attenuation factor "alpha"

(α) that represents the ratio of the indoor air concentration to the vapor concentration at a subsurface source. Using the attenuation factor and the appropriate target indoor air concentrations, contaminant concentrations in soil gas and groundwater that are protective of human health can be calculated, and these calculated values can be used as site cleanup goals.

The J/E model is most robust under homogeneous site conditions with uniform building construction features. Conversely, the model is weakest under variable conditions. Using a range of potential input parameters, the model can predict a wide range of indoor air impacts spanning over several orders of magnitude. Thus, when using the J/E model for California sites, the input parameters for a given facility must be appropriately conservative and match site-specific conditions. This is especially true for sites with nonbiodegradable chemicals, shallow to moderate depths of contamination, and a high advective potential (Hers et al., 2003). Hence, it is important to understand the sensitivity of the inputs parameters on the results of the model, and DTSC recommends that all vapor intrusion evaluations include a sensitivity analysis.

Evaluation of Vapor Intrusion Risk

DTSC recommends the use of a two-phased approach in evaluating the vapor intrusion at a facility. A phased approach ensures that simple cases can be evaluated relatively quickly with minimal resources. The first phase of the evaluation utilizes default attenuation factors to quickly quantify the risk for vapor intrusion (Step 5). Conservative assumptions, appropriate for California, were used to generate the default attenuation factors (see Appendix C). If the preliminary screening demonstrates that the risk associated with vapor intrusion is acceptable, no further evaluation for the exposure pathway is warranted.

After evaluating the risk with preliminary screening values, the responsible party has numerous options if the site risk is unacceptable. One option is further evaluation of the vapor intrusion risk through a site-specific evaluation (Step 7). A site-specific evaluation builds on a preliminary evaluation and utilizes conditions specific to the site concerning input parameters, land use, and exposure scenarios. The site-specific approach calls for increasingly sophisticated levels of data collection and analysis. Another option is site cleanup. The subsurface of the site can be remediated to the standards determined in the preliminary evaluation. Responsible parties may opt to pursue remediation without further site-specific modeling if the cleanup is time critical or if the volume of subsurface contamination is limited and can be remediated in a straightforward manner.

DISCUSSION OF MODELING INPUT PARAMETERS

The following input parameters should be used for all site-specific J/E modeling in California:

Indoor-Outdoor Pressure Differential (ΔP)	4 Pascals
Crack-to-Total Area Ratio (η)	0.005 (unitless)
Residential Indoor Air Exchange Rate (E_b)	0.5 hr ⁻¹
Commercial Indoor Air Exchange Rate (E_b)	1.0 hr ⁻¹

The basis of the selection of these input parameters is provided below. DTSC will consider the use of other modeling input parameters if an appropriate technical justification is provided.

Indoor-Outdoor Pressure Differential (ΔP)

Advective transport of soil vapors into buildings occurs as the result of the depressurization of buildings relative to the pressure in the surrounding soil. This indoor-outdoor pressure differential (ΔP), which is referred to as negative pressure, drives the flow of vapors into the building. The soil vapor flows into the building through cracks, gaps, and opening within the foundation. The pressure differential is caused by meteorological, mechanical, and occupant behavior factors. The meteorological factors include indoor-outdoor temperature differences (i.e., ‘stack effect’), wind loading on the building superstructure, and barometric pressure changes. Examples of mechanical and occupant behavioral factors that lead to building depressurization include the operation of exhaust fans, ceiling fans, fireplaces, and furnaces.

The potential range of values for indoor-outdoor pressure differential are 0 to 20 Pascals (1 Pa = 10 g/cm-s²) (Loureiro et al., 1990; Eaton and Scott, 1984). Individual values for indoor-outdoor pressure differential have been published as follows:

Author	Building Effect	ΔP values (Pascals)
Nazaroff et al., 1985; Put and Meijer, 1989	Wind and stack effects	2
Loureiro et al., 1990; Grimsrud et al., 1983	Wind and heating effects	4 -5
Fischer et al., 1996	Wind effects	3
Lindmark and Rosen, 1985	n/a	0 – 2*

* Buildings with mechanical ventilation and good insulation may have pressure differentials three times these values.

The above information indicates that some degree of negative pressure should be incorporated into any vapor intrusion evaluation. Quantifying the degree of building depressurization is a highly uncertain process. Due to this uncertainty and the inability to estimate the simultaneous interactions of all the depressurization factors, a value for building depressurization of 4 Pascals (40 g/cm-s²) was chosen as a conservative default for California.

Crack-to-Total Area Ratio (η)

The crack-to-total area ratio (η) is the ratio of the total area of cracks in the foundation and building floor available for vapor flow to the area of the floor. The parameter is also referred to as the “crack factor”. With respect to model sensitivity to crack factor, Johnson (2002) states that the J/E model is not sensitive to the selection of a crack factor for scenarios where advection dominates the movement of soil vapor. However, in scenarios where the intrinsic permeability of the soil is below 1.0E-9 centimeters per second squared, the movement of vapor will be dominated by diffusion and the selection of a crack factor becomes important. Johnson (2002) suggests that reasonable crack factor range from 0.0005 to 0.005. The American Society of Testing and Materials (1995) suggested a default value of 0.01 for the crack-to-total area ratio in their standard for risk-based corrective action. USEPA (2002b) used a crack factor of 0.0002 for houses with basements and 0.0038 for slab-on-grade houses. A value for crack factor of 0.005 was selected as a conservative default for California.

Indoor Air Exchange Rate (E_b)

Indoor air exchange is the principal mechanism for diluting indoor air contamination. The air exchange rate is defined as the number of times that the total volume of air within a building is replaced by external air, and the rate is usually expressed in terms of air exchanges per hour (i.e., hour^{-1}). Air within a building is exchanged through three processes; a) mechanical or forced ventilation, b) natural ventilation, and 3) infiltration. Mechanical or forced ventilation systems include the operation of exhaust fans, ceiling fans, fireplaces, and furnaces. Natural ventilation relates to occupant behaviors and activities like the opening and closing of doors and windows. Infiltration is defined as the uncontrolled airflow through foundation cracks, gaps, and opening. The infiltration of air is caused by indoor-outdoor temperature differences, wind loading on the building superstructure, and barometric pressure changes.

The scientific literature indicates that residential air exchange rates can range from 0.2 to 2.0 air exchanges per hour. Rates vary as a function of calendar season, building construction, building energy efficiency, and climatic conditions. Two nationwide studies of residential air exchange rates included data from California. Versar (1990) compiled about 100 separate field research projects by various organizations, which involved both random sampling and judgmental sampling. Most of the studies involved the use of perfluorocarbon (PFT) tracer gas to measure time-averaged air exchange rates. The PFT technique utilizes miniature permeation tubes as tracer emitters and passive samplers to collect the tracers, which were analyzed by gas chromatography. Murray and Burmaster (1995) also analyzed the PFT database and summarized distributions of exchange rates in subsets defined by climate and season. In this data evaluation, Murray and Burmaster lumped California data with other climatically appropriate states. A comprehensive review of residential indoor air exchange rates can be found in the Exposure Factors Handbook by USEPA (1997).

Air exchange rates for California are summarized below as taken from USEPA (1997). For residential buildings in California, a value of 0.50 air exchanges per hour should be used as a conservative default value. This value is approximately the 25th percentile of houses in California.

Summary of Air Exchange Rates for California						
Project Code	Month(s)	Percentiles				Number of Measurements
		10th	25th	50th	90th	
ADM	May - Jul	0.29	0.36	0.48	1.75	29
BSG	Jan, Aug - Dec	0.21	0.30	0.40	0.90	40
RT11	Feb	0.38	0.48	0.78	1.52	45
RT12	Jul	0.79	1.18	2.31	5.89	41
SOCAL1	Mar	0.29	0.44	0.66	1.43	551
SOCAL2	Jul	0.35	0.59	1.08	3.11	408
SOCAL3	Jan	0.26	0.37	0.48	1.11	330
weighted average		0.31	0.48	0.78	1.95	

Note: 1) Units are air exchange rates per hour.
 2) Data taken from USEPA (1997).

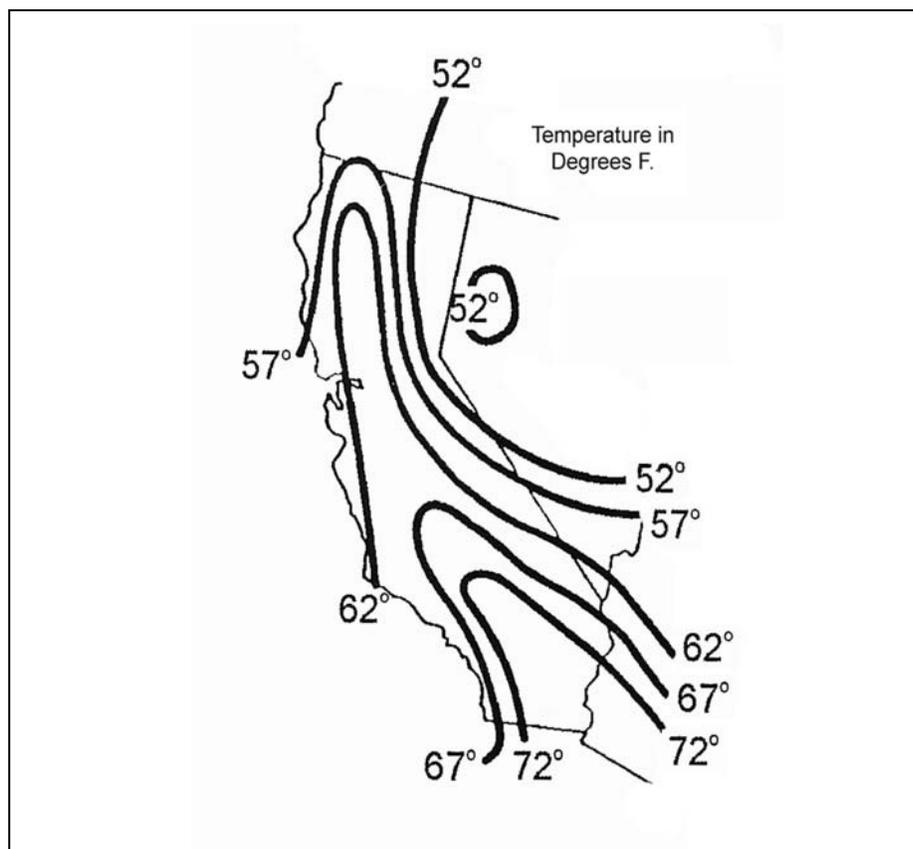
For commercial buildings, a default of 1.0 air exchange rate per hour should be used. This number is based upon the minimal ventilation requirements pursuant to the 2001 Energy Efficiency Standards for Nonresidential Buildings (California Energy Commission, 2001).

The minimum ventilation requirement is 0.15 cubic feet per minute per square foot of building space. For a single story commercial building, this equates to approximately 1.0 air exchanges per hour.

Average Soil and Groundwater Temperature

For vapor migration, the average soil and groundwater temperature is used to correct Henry's law constant to the appropriate subsurface temperature. When possible, the site-specific subsurface temperatures should be used when making the correction to Henry's law constant. During the routine sampling of monitoring wells, temperature is collected as a stabilization parameter during well purging. This temperature value can be used to make the Henry's law constant correction if monitoring wells exist at the site. If no monitoring wells exist at the site, the groundwater temperatures as collected at nearby sites can be used when the wells are screened within the water table. In cases where no subsurface temperature data are available, the subsurface temperature can be inferred from the isothermal contour lines shown in the map below. The map is from USEPA (1995) and shows the average temperature in shallow groundwater for California. Typically, in California, shallow groundwater temperatures range from 11 °C (Modoc Plateau) to 24 °C (Imperial Valley). Also, the subsurface temperature can be determined from the mean air temperature using the procedures from Toy et al. (1978).

Figure A-1: Groundwater Temperatures for California



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APPENDIX E - SOIL GAS CONCENTRATIONS FROM SOIL MATRIX ANALYTICAL RESULTS

When it is not possible to collect soil gas samples at a site, the vapor intrusion risk should be evaluated with soil matrix sample data as collected by USEPA Method 5035A. The associated soil gas concentration from the soil matrix data should be determined using the following partitioning calculation (Feenstra et al., 1991) and associated default parameters.

$$C_{\text{gas}} = \frac{HC_{\text{soil}} \rho_s}{(\theta_w + k_{\text{oc}} f_{\text{oc}} \rho_s + H \theta_a)}$$

where,

Input Parameter		Units	Default Value	Basis for Default Value
C_{gas}	Soil gas concentration	g/cm ³	Calculated	-
C_{soil}	Soil matrix concentration	g/g	Measured at site	-
θ_w	Soil volumetric water content	cm ³ /cm ³	0.15	Default for an unclassified soil
θ_a	Soil volumetric air content	cm ³ /cm ³	0.28	
ρ_s	Soil bulk density	g/cm ³	1.5	
f_{oc}	Soil fraction organic carbon	g/g	0.006	USEPA (2004)
H	Henry's Law constant	unitless	Chemical specific	-
k_{oc}	Carbon-water sorption coefficient	cm ³ /g	Chemical specific	-

g = grams
 cm³ = cubic centimeters

The above equation assumes equilibrium conditions exist in the subsurface that allow for the full partitioning of contaminants into their respective phases. Hence, the above equation should only be used with a full understanding of these potential limitations.

The maximum soil gas concentration, as determined from the soil matrix sampling, should be used for preliminary vapor intrusion evaluations pursuant to Step 5. For site-specific evaluations pursuant to Step 7, the soil gas contaminant source for the vapor intrusion modeling, as determined from the soil matrix sampling, can be statistically approximated if the sample collection is of sufficient density.

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APPENDIX F – USE OF PERMISSIBLE EXPOSURE LIMITS

Use of Occupational Safety and Health Administration (OSHA) Standards

The OSHA Permissible Exposure Limits (PELs) are not an appropriate standard for evaluating the risk associated with vapor intrusion to indoor air in California. Pursuant to the California Health and Safety Code, Sections 25150, 25187, 25200.10, and 25356, chemical releases in California should be characterized and mitigated based upon the risk to human and ecological receptors. Hence, for vapor intrusion sites, potential adverse effects to humans should be evaluated in terms of acceptable exposure based upon risk rather than upon comparison to OSHA PEL endpoints. For sites in California, regardless of whether the exposure scenario is residential, commercial, or industrial, OSHA PELs should not be used as exposure endpoints. DTSC regulates chemicals in the subsurface and any human exposure derived from the associated contaminant migration, and OSHA regulates workspace and any associated exposure derived from an industrial process. The one exception where OSHA PEL endpoints may be considered is for operating Resource Conservation and Recovery Act (RCRA) facilities pursuant to USEPA's Environmental Indicators Program discussed below.

OSHA regulates exposure to chemicals in an industrial setting. OSHA regulations prescribe controls and monitoring of the workplace environment to lessen employee exposure to vapors and gases. For employees working in an environment where they may be exposed to vapors and gases that exceed the PELs, training, medical surveillance, personnel monitoring, exposure information, and respiratory protection must be available. Those workplaces that handle volatile materials must control exposure to employees, which is typically done with ventilation systems, process enclosures, work practices, and personal protection equipment. OSHA requires that employees have access to Material Safety Data Sheets (MSDSs) and that employees are trained to recognize hazardous conditions. Hence, workers subject to potential exposure to gases and vapors by the nature of their working environment are regulated under OSHA. These workplaces are usually commercial and industrial settings where hazardous chemicals are handled inside a building as part of a commercial or industrial process. Employees working with a commercial or industrial process that involves hazardous gases or vapors usually work in these conditions voluntarily, are aware of the potential risk of exposure, and have implicitly accepted exposure as an occupational hazard.

For gases and vapors, the PEL is the maximum concentration of a chemical in the air that a worker may be exposed to without respiratory protection (California Code of Regulations, Title 8, section 5155). Exposure to PELs is assumed to occur to healthy workers. OSHA did not envision that children, the elderly, or unhealthy adults would be exposed to PEL concentrations. Therefore, OSHA PEL endpoints are not an appropriate health-protective standard for evaluating the risk associated with vapor intrusion to indoor air in California.

At sites subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), cleanup levels are generally determined either by Applicable or Relevant and Appropriate Requirements (ARARs) or the risk assessment process. OSHA standards are not ARARs under CERCLA statute and regulations. Therefore, OSHA standards should not be applied to CERCLA cleanups.

USEPA Environmental Indicators Program

The use of OSHA PELs as an endpoint for exposure due to the vapor intrusion pathway can only be done in one situation within California. OSHA PELs can be used to evaluate RCRA sites subject to the Government Performance and Results Act (GPRA) of 1993. Under GPRA, USEPA is required to prepare strategic plans and associated timeframes for controlling human exposure and contaminant migration in groundwater at RCRA sites. The Environmental Indicators (EI) Program is USEPA's method of tracking progress for attainment of the GPRA goals. USEPA measures the ability of RCRA facilities to control human exposure to contaminated environmental media, including exposure to contaminated indoor air due to vapor intrusion. As an interim approach for evaluating human exposure due to vapor intrusion into buildings, USEPA allows the use of OSHA PELs at operating RCRA sites as a way to evaluate progress on corrective action activities (USEPA, 2003a). The OSHA PELs are used only at operating RCRA sites as an interim measure to evaluate buildings that house a commercial or industrial process. These buildings must house a process that involves the use of chemicals that are similar to the chemicals subject to vapor intrusion due to prior releases to the environment. Additionally, the workers in these buildings must be subject to Occupational Safety and Health Standards pursuant to Title 29, Code of Federal Regulations. For final remedies at RCRA corrective action sites, risk-based standards are used rather than OSHA PEL endpoints.

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APPENDIX G - SOIL GAS SAMPLING DIRECTLY UNDER BUILDING FOUNDATIONS (SUBSLAB SAMPLING)

For sites that fail a preliminary evaluation pursuant to Step 5, a site-specific evaluation of vapor intrusion can be done, which may include the sampling of soil gas beneath a building's foundation. The number and locations of subslab samples should be determined based on information collected during the building survey, an understanding of the building foundation, and the results from nearby soil gas sampling. At least two subslab samples should be taken at a minimum, with one sample taken in the center of the building's foundation, if possible. The subslab data will determine if vapors are collecting directly under the building's foundation and will demonstrate which contaminants potentially represent a threat to human health. If a building is determined to have a vapor barrier and/or a tension slab, special care should be given when hand-drilling through the concrete slab. In particular, for a tension foundation slab, the tension cables within the slab should be located prior to drilling either through visual observation or through remote-sensing with either a metal detector or ground penetrating radar. The cutting of a tension cable within a slab during drilling could disrupt the integrity of the slab and potentially cause injury to the field crew.

When evaluating subslab soil gas concentrations for a building, DTSC recommends that permanent sampling points be installed so that repeated sampling can be conducted, as necessary, to evaluate seasonal or temporal variations.

The following guidelines for subslab testing are derived, with modifications, from the state of Massachusetts' Indoor Air Sampling and Evaluation Guide, WSC Policy #02-430 (Massachusetts Department of Environmental Protection, 2002).

- 1) After removal of the floor covering, small-diameter holes should be drilled through the concrete of the foundation slab. Typically, holes are 1.0 to 1.25 inches in diameter. Either an electric hand drill or concrete corer is used to drill the holes. All subslab utilities should be located and clearly marked on the slab prior to drilling. Subslab holes should be advanced 3 to 4 inches into the subslab material. The sampling probe should be constructed with the following specifications:
 - Vapor probes are typically constructed of 1/8 inch or 1/4 inch diameter brass or stainless steel pipe, with a permeable probe tip. A Teflon™ sealing disk should be placed between the probe tip and the blank pipe.
 - Bentonite chips should be used to fill the borehole annular space between the probe pipe and subslab gravel from the Teflon sealing disk to the base of the concrete foundation. Sufficient water should be added to hydrate the bentonite to insure proper sealing, and care should be used in placement of the bentonite to prevent post-emplacment expansion which might compromise both the probe and cement seal. If needed, the vapor probe tip can be covered with sand.
 - The probe pipe should be tightly sealed to the foundation slab with quick-setting contaminant-free Portland cement.

- Each probe should be constructed with a recessed threaded cap with a brass or stainless steel threaded fitting or compression fitting so the probe completion is flush with the foundation slab to reduce the tripping hazard.
- At least 30 minutes of time should elapse following installation of a probe to allow the cement to cure and allow for the subsurface conditions to equilibrate prior to sampling.

An example of a sampling probe is shown in the attached schematic diagram.

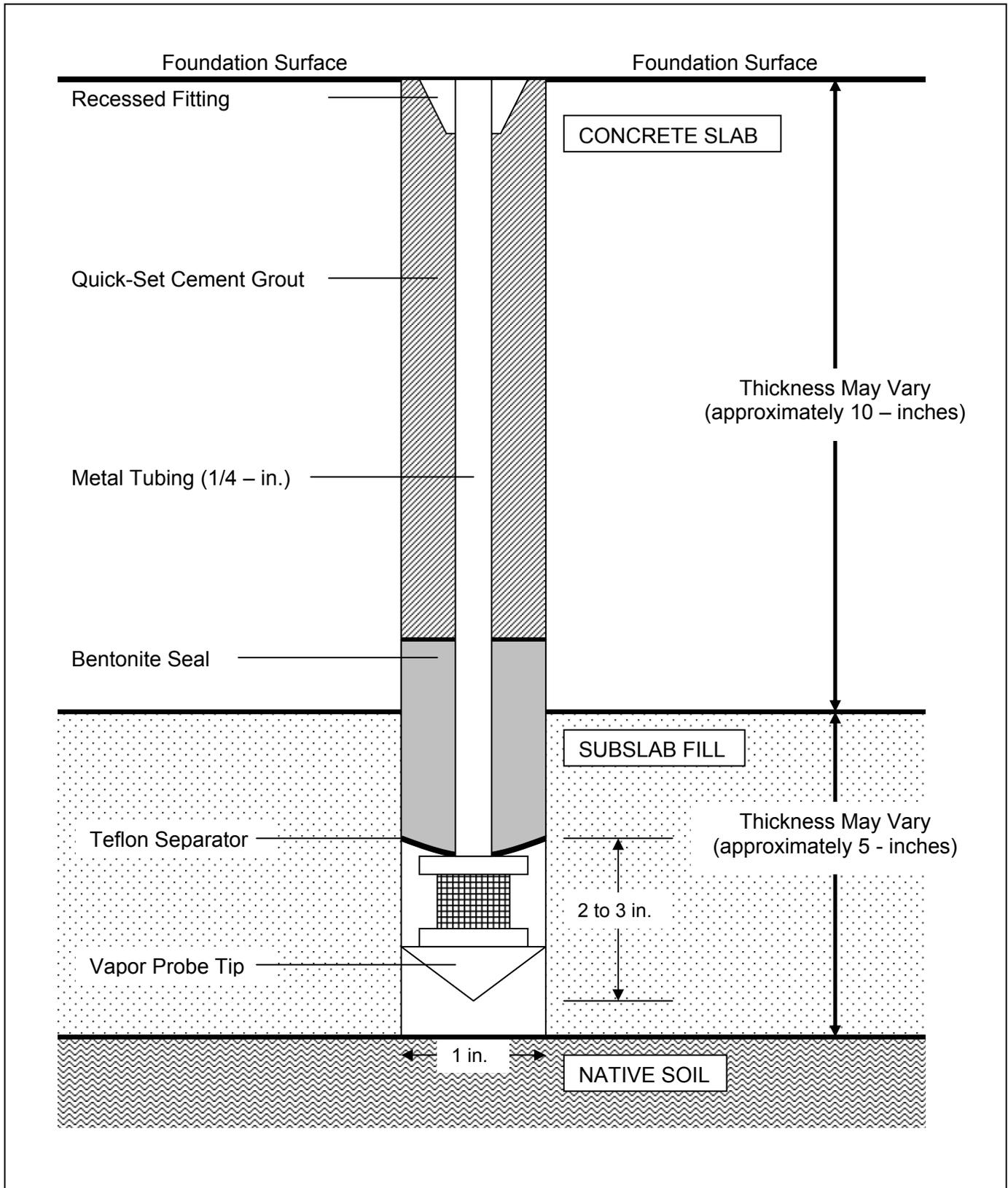
- 2) The collection of subslab samples should follow the procedures in Cal-EPA (2003), which recommends purge volume testing, leak testing, and the use of surface seals to insure sample integrity, as appropriate for field conditions. Samples should be collected in gas-tight, opaque/dark containers so that light-sensitive or halogenated VOCs will not degrade. The use of Tedlar bags for collection of soil gas samples is not recommended. If a Summa™ canister is used, a flow regulator should be placed between the probe and the canister to ensure that the canister is filled at the appropriate flow rate. Flow rates should not exceed 200 ml/min. Care should be taken during sampling to avoid sample break-through from the surface of the slab.
- 3) Subslab soil gas sampling should be performed using analytical methods in Cal-EPA (2003). These methods include USEPA Methods 8260B, 8021B, and 8015B. Other methods that may be used include USEPA Methods TO-14A, TO-15, and other methods that meet the site-specific data quality objectives and the analytical method detection limits for risk determination.
- 4) A sufficient number of subslab sampling events should be conducted to account for seasonal and temporal transience. Therefore, a minimum of two subslab sampling events are warranted before a final risk determination is made.
- 5) Upon completion of all the sampling, the foundation probes should be properly decommissioned. The probe tip, probe piping, bentonite, and grout should be removed by re-drilling. The borehole should be filled with grout and concrete patch material. Surface restoration should include a follow-up visit for final sanding and finish work to restore the floor slab to its original condition.

The use of passive soil gas methods for subslab sampling are not recommended for risk determination. Passive soil gas sampling should only be considered to identify subsurface contaminants, preferential pathways for vapor movement, and to reduce uncertainty caused by temporal variations.

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SCHEMATIC DIAGRAM OF A SUBSLAB SAMPLING PROBE



APPENDIX H – SOIL LABORATORY MEASUREMENTS

For site-specific evaluations of vapor intrusion, determination of the physical properties of the vadose zone may be needed. If so, soil samples should be collected for the evaluation of the physical character of the subsurface during site characterization. Soil can be submitted to a laboratory for the measurement of bulk density, grain density, total porosity, moisture content, fraction organic carbon, and grain size. The recommended geotechnical laboratory methods are:

Soil Bulk Density	ASTM D2937.
Grain Density	ASTM D854.
Total Porosity	Calculate from the soil bulk density and the grain density.
Soil Moisture Content	ASTM D2216.
Fraction Organic Carbon	Walkley-Black method (Nelson and Sommers, 1992).
Grain Size	ASTM D422.

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APPENDIX I – IN-SITU SOIL AIR PERMEABILITY MEASUREMENTS

For site-specific evaluations of vapor intrusion, determination of the air permeability of the shallow soil may be needed. In these cases, air permeability measurements can be conducted using the same equipment that is used to collect soil gas samples. Permeabilities are determined by measuring the gas pressure in a vapor probe or well bore as a metered flow of air is passed through the probe or well into the soil.

The measurement of in-situ air permeability should be conducted at depths of five feet or less, which is the approximate depth of the building-driven advective movement of vapors in the USEPA Vapor Intrusion Model. However, these air injection tests should only be conducted after soil gas samples have been obtained because the injected gas will distort subsurface concentration measurements.

The following equation can be used to determine in-situ air permeability. The equation has been adapted from an analytical expression by Hvorslev (1951) and Hsieh et al. (1983) for the spatial distribution of steady-state water pressure around an injection interval. Derivation of the equation can be found in Bassett et al. (1994) and field application of the equation can be found in Guzman (1995). The validity of the method is further discussed in Illman and Neuman (2000) and Vesselinov and Neuman (2001). The equation assumes that, during each relatively stable period of air injection, air is the only mobile phase within the soil near the test interval and is controlled by a steady-state pressure field with prolate spheroidal symmetry. Such symmetry implies that the soil forms a uniform, isotropic porous continuum. The equation is:

$$k = Q_{sc} \frac{\mu \ln(L/r_w) T_{sc} Z}{\pi L (p^2 - p_o^2) T_{sc}}$$

where,

- k = air permeability (m²)
- Q_{sc} = volumetric air flow rate at standard conditions (m³/s)
- μ = dynamic viscosity of air at standard conditions (1.81 x 10⁻⁵ pascal-s)
- ln = natural logarithm operator
- L = length of the test interval (m)
- r_w = borehole radius (m)
- T = air temperature in the test interval (° Kelvin)
- p_{sc} = air pressure at standard conditions (101,300 pascals)
- Z = air compressibility factor (assume 1.0 [unitless])
- π = pi (3.1416)
- p = air pressure in the injection interval (pascals)
- p_o = ambient air pressure during injection (pascals)
- T_{sc} = temperature at standard conditions (273° Kelvin)

After obtaining a soil gas sample from a borehole, air is injected into the soil probe or well and the pressure and the flow rate of the air are measured at the surface. To conduct the permeability measurements, a cylinder of compressed air can be used as an injection source, along with a flow meter with a range of 5 to 500 cubic centimeters per minute, and a differential pressure gauge with a range of 0 to 125 pascals. To obtain differential pressure

measurements over the required range, multiple pressure gauges may be needed, because a single gauge will not yield the required measurement range. The following guidance should be considered when collecting and evaluating in-situ air permeability data:

- The injection test should continue until steady-state pressure occurs. The occurrence of steady-state pressure is defined as less than a 50 pascals pressure change within 30 minutes. The test should be terminated after 4 hours if pressure stabilization is not obtained.
- During the first hour of the test, injection pressure, flow rate, injection temperature, and barometric pressure should be measured at five minute intervals, or as appropriate. After the first hour, data can be collected less frequently but at a minimum interval of 30 minutes.
- The air permeability should be calculated with the data obtained during steady-state conditions.
- The diameter on the probe tip used for air injection should be measured to within ± 0.01 inches before insertion into the soil and then remeasured upon retrieval from the subsurface to verify no probe diameter distortion occurred during installation.
- The above equation is based on the assumption that the flow of injection air is predominantly radial, which is assumed to occur when L/r_w is greater than 5 (Bassett et al., 1994). Hence, this ratio of greater than 5 must occur during all air permeability testing. Otherwise, the above is equation cannot be used to calculate air permeability and an alternate method within Bassett et al. (1994) should be followed.
- The air compressibility factor in the above equation indicates the extent which the injection air behaves as an ideal gas. The assumption that the air compressibility factor is 1.0 assumes the injected gas behaves as an ideal gas. If site conditions indicate non-ideal gas behavior, the above equation should not be used to determine in-situ air permeability.

The use of a single small diameter probe may systematically underestimate the in-situ air permeability due to the measurement length scale (Garbesi et al., 1996; Garbesi et al., 1999). Thus, when possible, numerous air permeability measurements should be conducted as a means to evaluate the underprediction.

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- Vesselinov, V., and S. P. Neuman. 2001. Numerical Inverse Interpretation of Single-Hole Pneumatic Tests in Unsaturated Fractured Tuff. *Groundwater*, v. 39, n. 5, p. 685 – 695.

APPENDIX J – EXAMPLE ACCESS AGREEMENT

AUTHORIZATION AND RELEASE

I hereby authorize the California Department of Toxic Substances Control and its authorized agents to obtain soil, soil gas, or groundwater samples from my property in the (*NAME OF CITY, NAME OF COUNTY*), California, for the purpose of characterizing the extent of (*SPECIFY THE CHEMICAL(S) TO BE COLLECTED*) in the subsurface. The sampling will be performed between the hours of ____ and ____.

I understand that persons entitled to access by this Authorization and Release include the Department of Toxic Substances Control, its officers, agents, employees, contractors, and any other person authorized by the Department of Toxic Substances Control, to perform the above activities.

I understand that such sampling may involve disturbance of the soil, lawn and vegetation. Therefore, I should advise the Department of Toxic Substances Control agents of the location of sprinkler systems, pipes, drains, etc. The Department of Toxic Substances Control will use reasonable effort to return the property to its condition prior to sampling. I agree to hold harmless the agents of the Department of Toxic Substances Control for any and all damages resulting from the sampling.

I understand that the Department of Toxic Substances Control will not be providing a duplicate sample, but will make available to me the analytical results of all sampling activities.

Name of Resident

Telephone Number

Resident Address

City / State / Zip Code

Property Owner Signature

Date

APPENDIX K - BUILDING SURVEY FORM

This form must be completed for each building involved in an indoor air investigation.

Preparer's name _____ Date prepared _____

Preparer's affiliation _____

Telephone number _____

1. OCCUPANT

Name _____

Address _____

City _____

Home telephone number _____

Office telephone number _____

2. OWNER OR LANDLORD

Name _____
(If different than occupant)

Address _____

Telephone number _____

A. Type of Building Construction

Type (circle appropriate responses): Single Family Multiple Dwelling Commercial

Ranch	Two-family
Raised Ranch	Duplex
Split Level	Office
Colonial	Warehouse
Mobile Home	Strip Mall
Apartment Building:	Number of Units _____
Other _____	

Building Age _____ Number of stories _____

Area of the Building (square feet) _____

Is the building insulated? yes / no How sealed is the building? _____

Number of elevators in the building _____

Condition of the elevator pits (sealed, open earth, etc.) _____

General description of building construction materials _____

B. Foundation Characteristics (circle all that apply)

1. Full basement, crawlspace, slab on grade, other _____
2. Basement floor description: concrete, dirt, wood, other _____
 - a. The basement is: wet, damp, dry _____
 - b. Sump present? yes / no _____ Water in sump? yes / no _____
 - c. The basement is: finished, unfinished _____
 - d. Is the basement sealed? Provide a description _____

3. Concrete floor description: unsealed, painted, covered; with _____
4. Foundation walls: poured concrete, block, stone, wood, other _____
5. Identify all potential soil gas entry points and their size (e.g., cracks, voids, pipes, utility ports, sumps, drain holes, etc.). Include these points on the building diagram.

C. Heating, Ventilation, and Air Conditioning (circle all that apply)

1. The type of heating system(s):

Hot Air Circulation	Heat Pump
Hot Water Radiation	Unvented Kerosene Heater
Steam Radiation	Wood Stove
Electric Baseboard	Other (specify) _____
2. The type of fuel used: Natural Gas, Fuel Oil, Electric, Wood, Coal, Solar
Other (specify) _____
3. Location of heating system: _____
4. Is there air-conditioning? yes / no Central Air or Window Units?

Specify the location _____

5. Are there air distribution ducts present? yes / no
6. Describe the supply and cold air return duct work including whether there is a cold air return and comment on the tightness of duct joints.

-
7. Is there a whole house fan? yes / no _____
What is the rated size of the fan? _____

8. Temperature settings inside during sampling. Note day and night temperatures.
 - a. Daytime temperature(s) _____
 - b. Nighttime temperature(s) _____
(Note times if system cycles during non-occupied hours during the day)

9. Estimate the average time doors and windows are open to allow fresh outside air into the building. Note rooms that frequently have open windows or doors.
-

D. Potential Indoor Sources of Pollution

1. Is the laundry room located inside the home? yes / no
 2. Has the house ever had a fire? yes / no
 2. Is there an attached garage? yes / no
 3. Is a vehicle normally parked in the garage? yes / no
 4. Is there a kerosene heater present? yes / no
 5. Is there a workshop, hobby or craft area in the residence? yes / no
 6. An inventory of all products used or stored in the home should be performed. Any products that contain volatile organic compounds or chemicals similar to the target compounds should be listed. The attached product inventory form should be used for this purpose.
 7. Is there a kitchen exhaust fan? yes / no Where is it vented? _____
 8. Is the stove gas or electric? _____ Is the oven gas or electric? _____
 9. Is there an automatic dishwasher? yes / no
 10. Is smoking allowed in the building? yes / no
 11. Has the house ever been fumigated or sprayed for pests? If yes, give date, type and location of treatment.
-

E. Water and Sewage (Circle the appropriate response)

Source of Water

Public Water Drilled Well Driven Well Dug Well Other (Specify) _____

Water Well Specifications

Well Diameter _____ Grouted or Ungouted _____

Well Depth _____ Type of Storage Tank _____

Depth to Bedrock _____ Size of Storage Tank _____

Feet of Casing _____ Describe type(s) of Treatment _____

Water Quality

Taste and/or odor problems with water? yes / no If so, describe _____

Is the water chlorinated, brominated, or ozonated? yes / no _____

How long has the taste and/or odor problem been present? _____

Sewage Disposal: Public Sewer Septic Tank Leach Field Other (Specify) _____

Distance from well to septic system _____ Type of septic tank additives _____

F. Plan View

Sketch each floor and if applicable, indicate air sampling locations, possible indoor air pollution sources, preferential pathways and field instrument readings.

G. Potential Outdoor Sources of Pollution

Draw a diagram of the area surrounding the building being sampled. If applicable, provide information on the spill locations (if known), potential air contamination sources (industries, service stations, repair shops, retail shops, landfills, etc.), outdoor air sampling locations, and field instrument readings.

Also, on the diagram, indicate barometric pressure, weather conditions, ambient and indoor temperatures, compass direction, wind direction and speed during sampling, the locations of the water wells, septic systems, and utility corridors if applicable, and a statement to help locate the site on a topographical map.

